

# Chapter 12

## **NERVOUS TISSUE**

# INTRODUCTION

- The *nervous system*, along with the endocrine system, helps to keep controlled conditions within limits that maintain health and helps to maintain homeostasis.
- The nervous system is responsible for all our behaviors, memories, and movements.
- The branch of medical science that deals with the normal functioning and disorders of the nervous system is called *neurology*.

# OVERVIEW OF THE NERVOUS SYSTEM

# Structures and Functions of the Nervous System

# Nervous System

- The *nervous system* is made up of the brain, cranial nerves, spinal cord, spinal nerves, ganglia, enteric plexus, and sensory receptors.
- The *brain* is housed within the skull.
- Twelve pairs of ***cranial nerves*** emerge from the base of the brain through foramina of the skull.
- A *nerve* is a bundle of hundreds or thousands of axons, each of which courses along a defined path and serves a specific region of the body.

# Spinal Cord

- The *spinal cord* connects to the brain through the foramen magnum of the skull and is encircled by the bones of the vertebral column.
- **Thirty-one pairs** of *spinal nerves* emerge from the spinal cord, each serving a specific region of the body.
- *Ganglia*, located outside the brain and spinal cord, are small masses of nervous tissue, containing primarily cell bodies of neurons.

# Plexuses

- *Enteric plexuses* help regulate the digestive system.

# Sensory Receptors

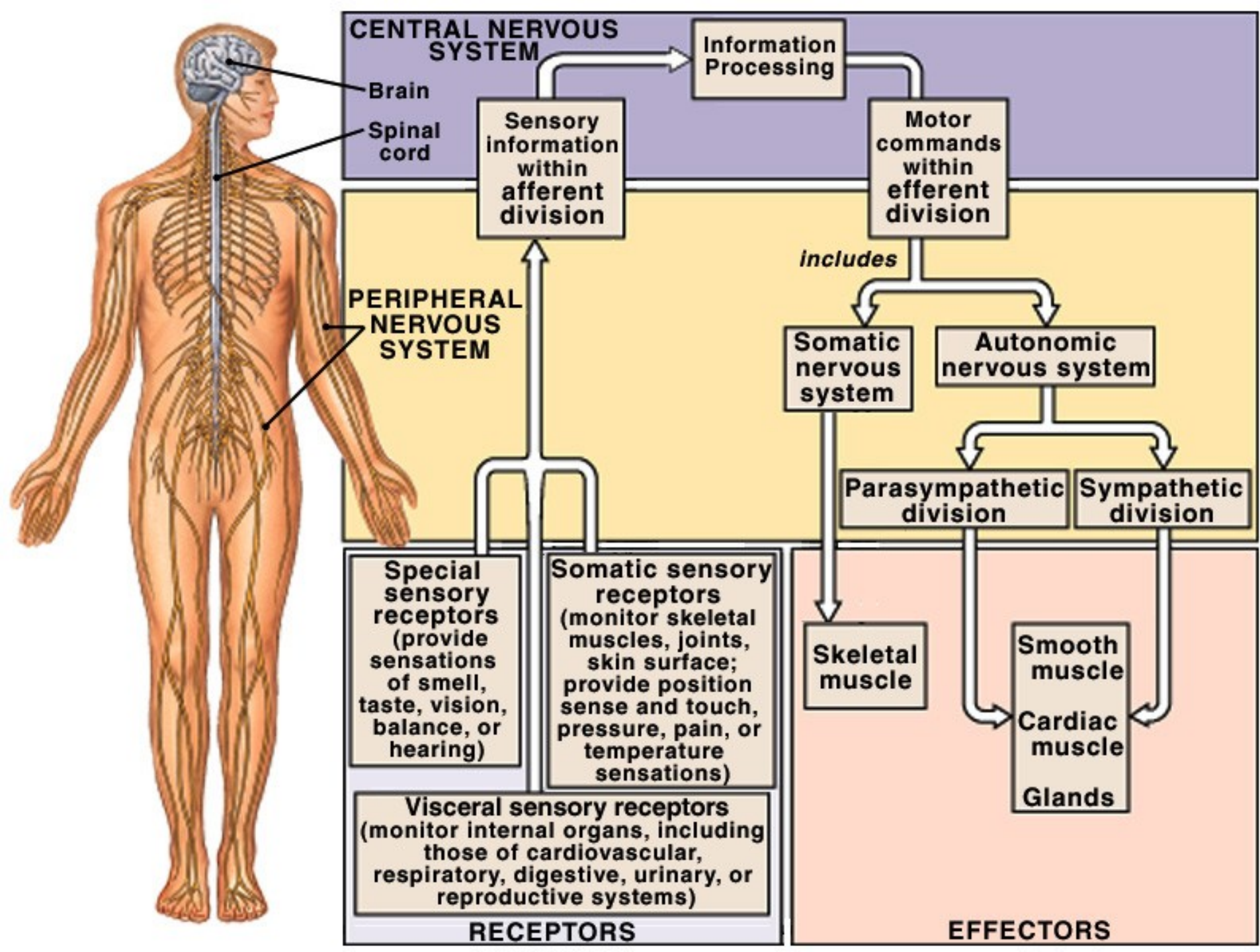
- **Sensory receptors** are either parts of neurons or specialized cells that monitor changes in the internal or external environment.
- The three basic functions of the nervous system are sensory, integrative, and motor.
- The **sensory function** of the nervous system is to sense changes in the internal and external environment through sensory receptors.
- **Sensory neurons** serve this function.

# Other Functions

- The *integrative function* is to analyze the sensory information, store some aspects, and make decisions regarding appropriate behaviors.
- **Association** or **interneurons** serve this function.
- The **motor function** is to respond to stimuli by initiating action.
- **Motor neurons** serve this function.

# Organization of the Nervous System

- The ***central nervous system*** (**CNS**) consists of the brain and spinal cord.
- The ***peripheral nervous system*** (**PNS**) consists of cranial and spinal nerves with sensory (**efferent**) and motor (**afferent**) components, ganglia, and sensory receptors.
- The ***sensory system*** consists of a variety of different receptors as well as sensory neurons.
- The ***motor system*** conducts nerve impulses from the **CNS** to muscles and glands.



# Peripheral Nervous System (PNS)

- The PNS is also subdivided into **somatic** (voluntary), **autonomic** (involuntary), and **enteric** nervous systems.

# Somatic Nervous Systems (SNS)

- The ***somatic nervous system*** (SNS) consists of neurons that conduct impulses from cutaneous and special sense receptors to the CNS, and motor neurons that conduct impulses from the CNS to skeletal muscle tissue.

# Autonomic Nervous System (ANS)

- The *autonomic nervous system* (**ANS**) contains sensory neurons from visceral organs and motor neurons that convey impulses from the CNS to smooth muscle tissue, cardiac muscle tissue, and glands.

# ANS Divisions

- The motor part of the ANS consists of the ***sympathetic division*** and the ***parasympathetic division***.
- Usually, the two divisions have opposing actions.

## PERIPHERAL NERVOUS SYSTEM

## CENTRAL NERVOUS SYSTEM

Exteroceptors

Proprioceptors

Interoceptors

Skeletal muscles

Skeletal muscle fibers



Visceral effectors

Smooth muscles



Glands



Cardiac muscle



Adipose tissue



Sensory neurons

in  
peripheral ganglia

Afferent fibers

Efferent fibers

Visceral motor neurons  
in peripheral  
motor ganglia

Postganglionic  
fibers

Preganglionic  
fibers

Interneurons

Somatic  
motor  
neurons

Visceral  
motor  
neurons  
in CNS

→ Somatic (sensory & motor)

→ Visceral (sensory & motor)

# Enteric Nervous System (ENS)

- The *enteric nervous system* (**ENS**) consists of neurons in enteric plexuses that extend the length of the GI tract.
- Many neurons of the enteric plexuses function independently of the ANS and CNS.
- Sensory neurons of the ENS monitor chemical changes within the GI tract and stretching of its walls, whereas enteric motor neurons govern contraction of GI tract organs, and activity of the GI tract endocrine cells.

# HISTOLOGY OF THE NERVOUS SYSTEM

# NERVE TISSUE

- Unique cells => specialized tissue
  - Functional specialization
    - Excitable: conductivity
    - Integrative: sensory/motor
  - Structural specialization
    - Cellular processes
    - Interconnections

# TYPES OF CELLS

- Neuroglia
- Neurons
- Neuroendocrine

# HISTO-PHYSIOLOGY OF THE GLIA

# Structural and Functional Variations in Neurons

- Most neurons in the body are **interneurons** and are often named for the histologist who first described them.
- Examples are *Purkinje cells* or Renshaw cells.
- Interneurons named for the **shape** or appearance include *pyramidal cells*.

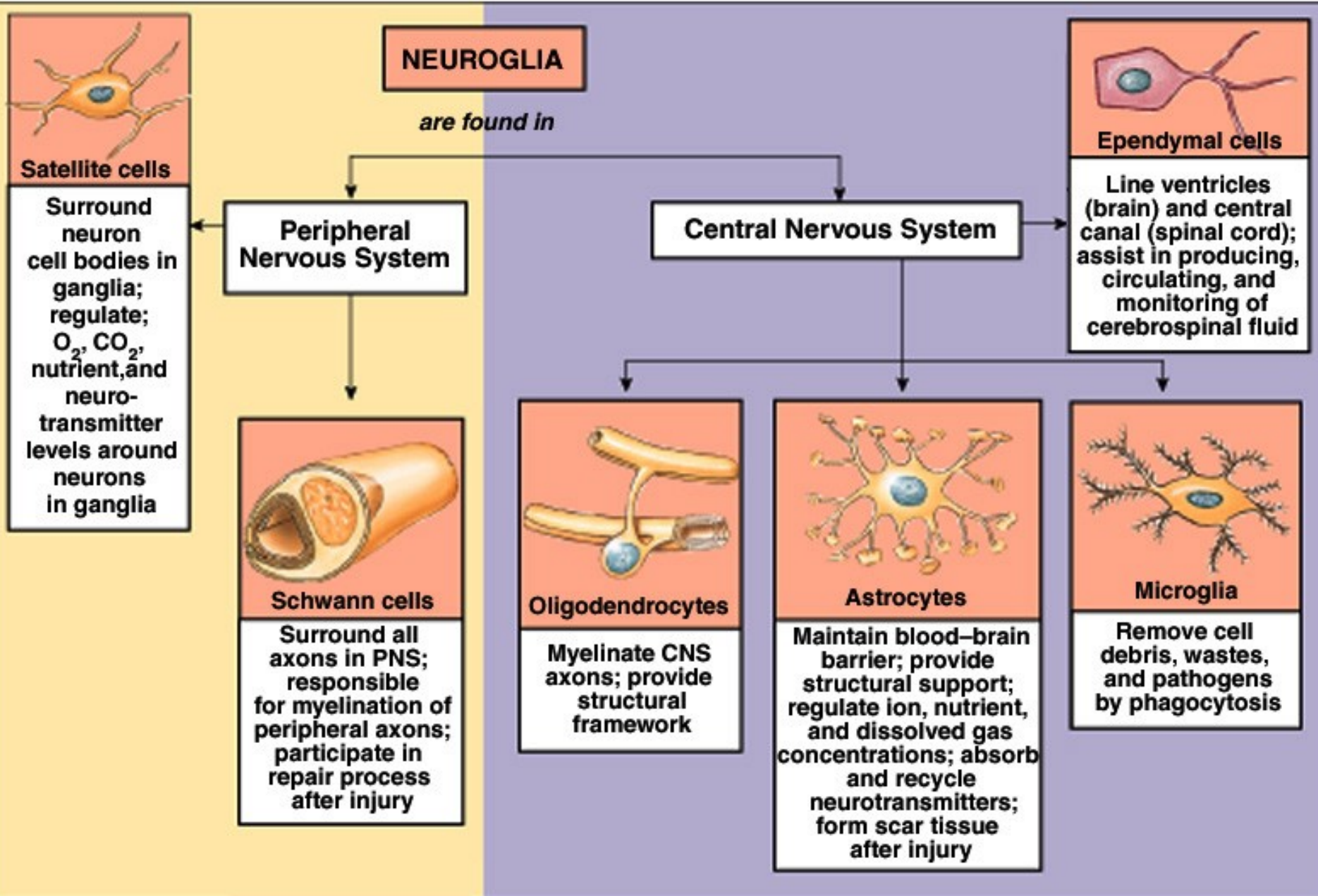
# NEUROGLIA

- ***Neuroglia*** (or glia) are specialized tissue cells that support neurons, attach neurons to blood vessels, produce the myelin sheath around axons, and carry out phagocytosis.
- Table 12.1 summarizes the types of neuroglia.

# NEUROGLIA

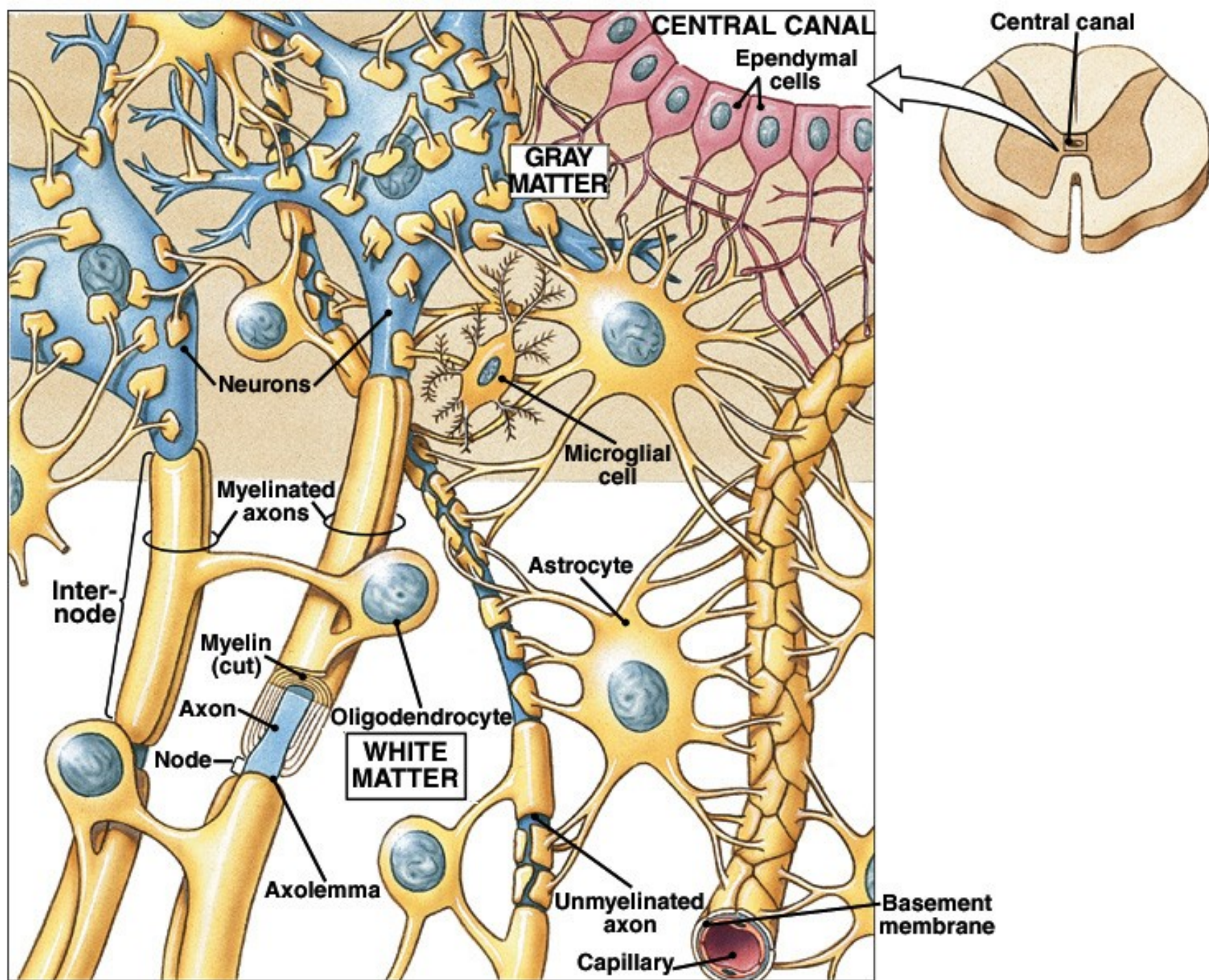
- Ependymal cells
- Astrocytes
- Microglia
- Satellite cells
- Oligodendrocytes
- Schwann cells

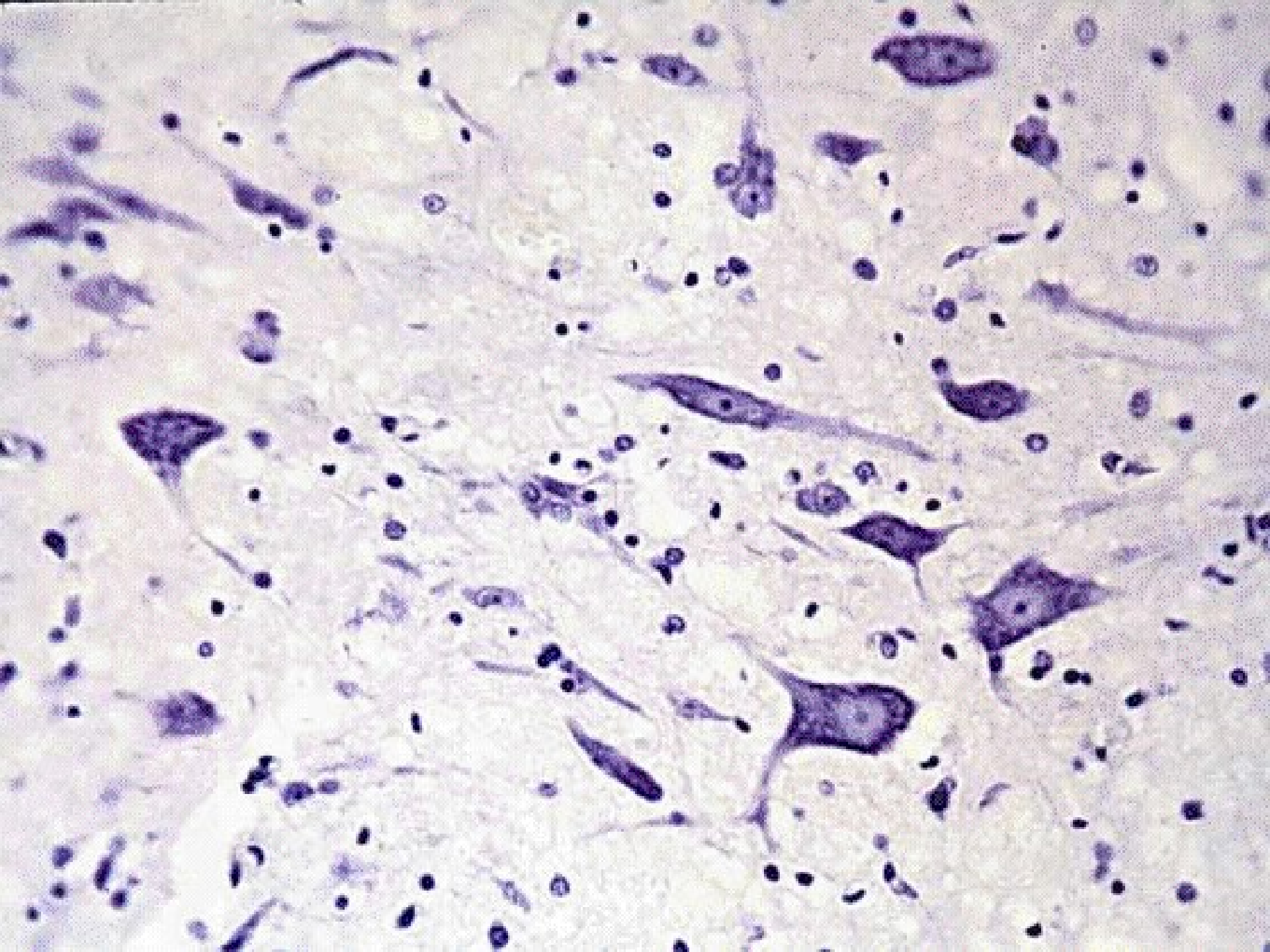
# FUNCTION OF NEUROGLIA

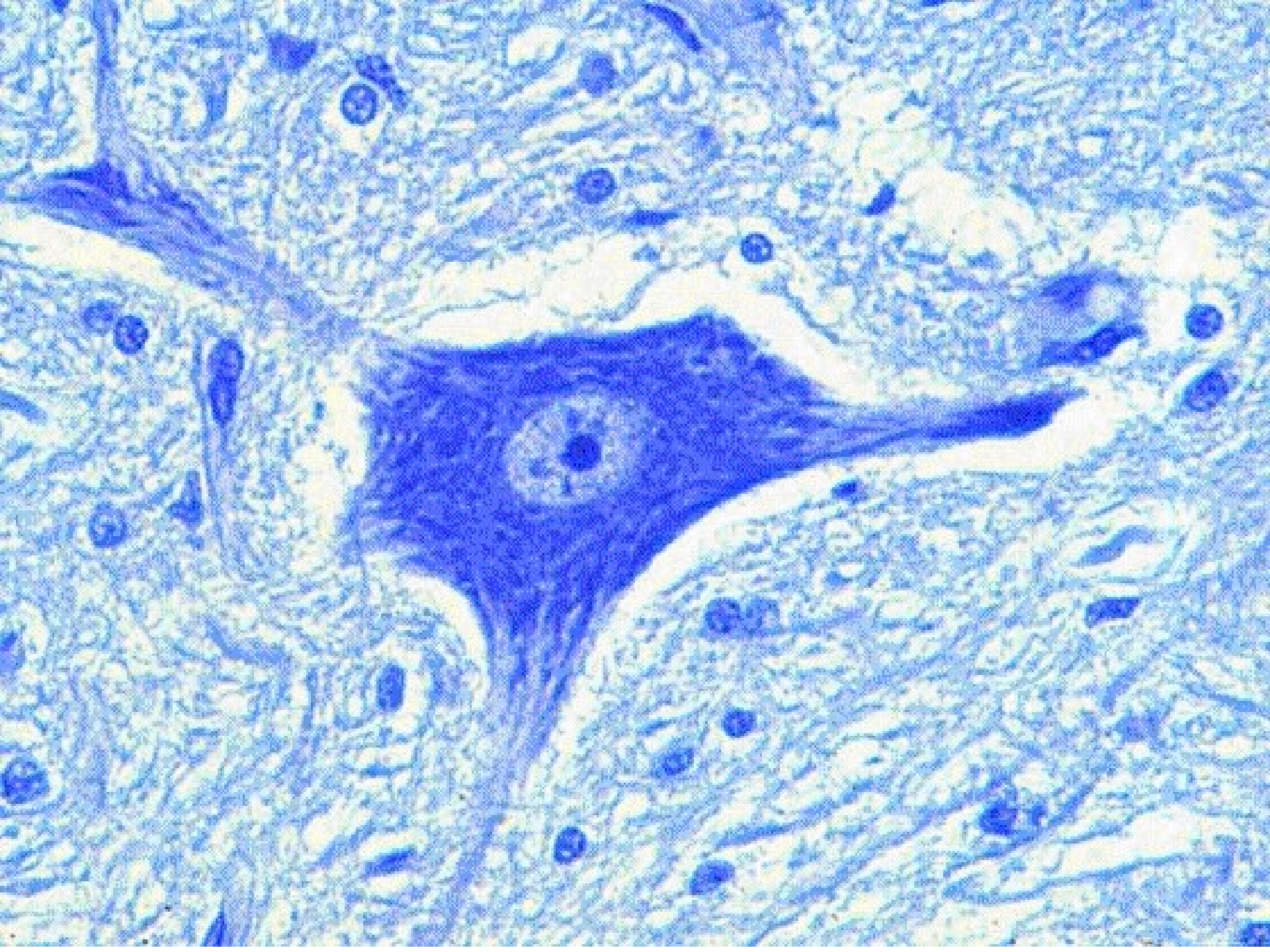


# FUNCTIONS

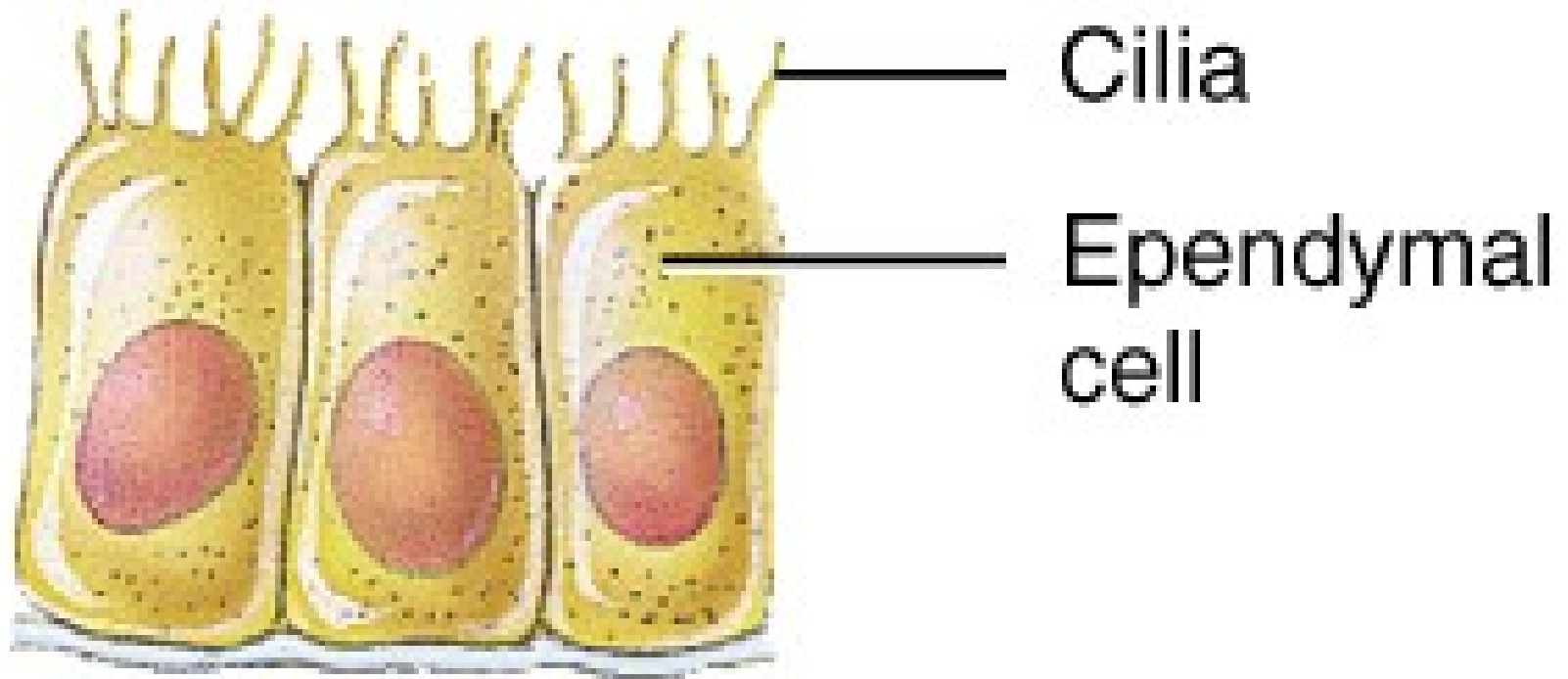
- Support neurons
  - 10 to 50x more numerous
- Do NOT generate **action potentials**
- “Connective” component of NS
- Phagocytic
- Buffer ions ( $K^+$ )
- Insulate fibers (myelination)

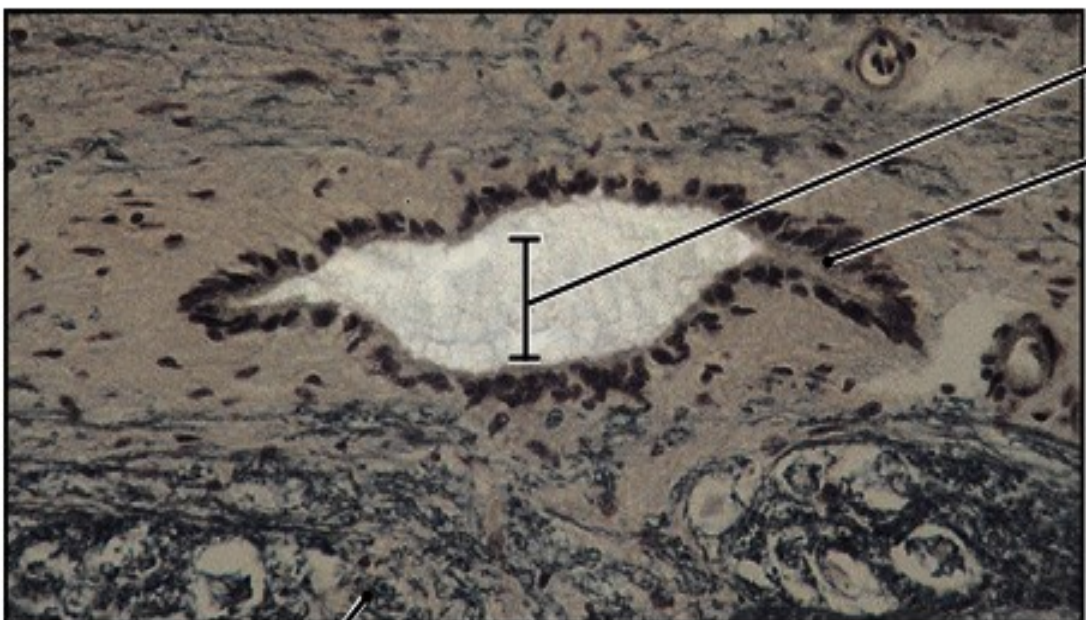






# EPENDYMAL CELLS

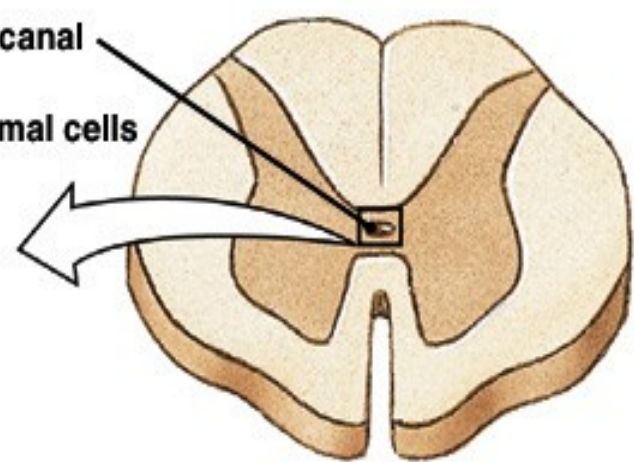




Central canal

Ependymal cells

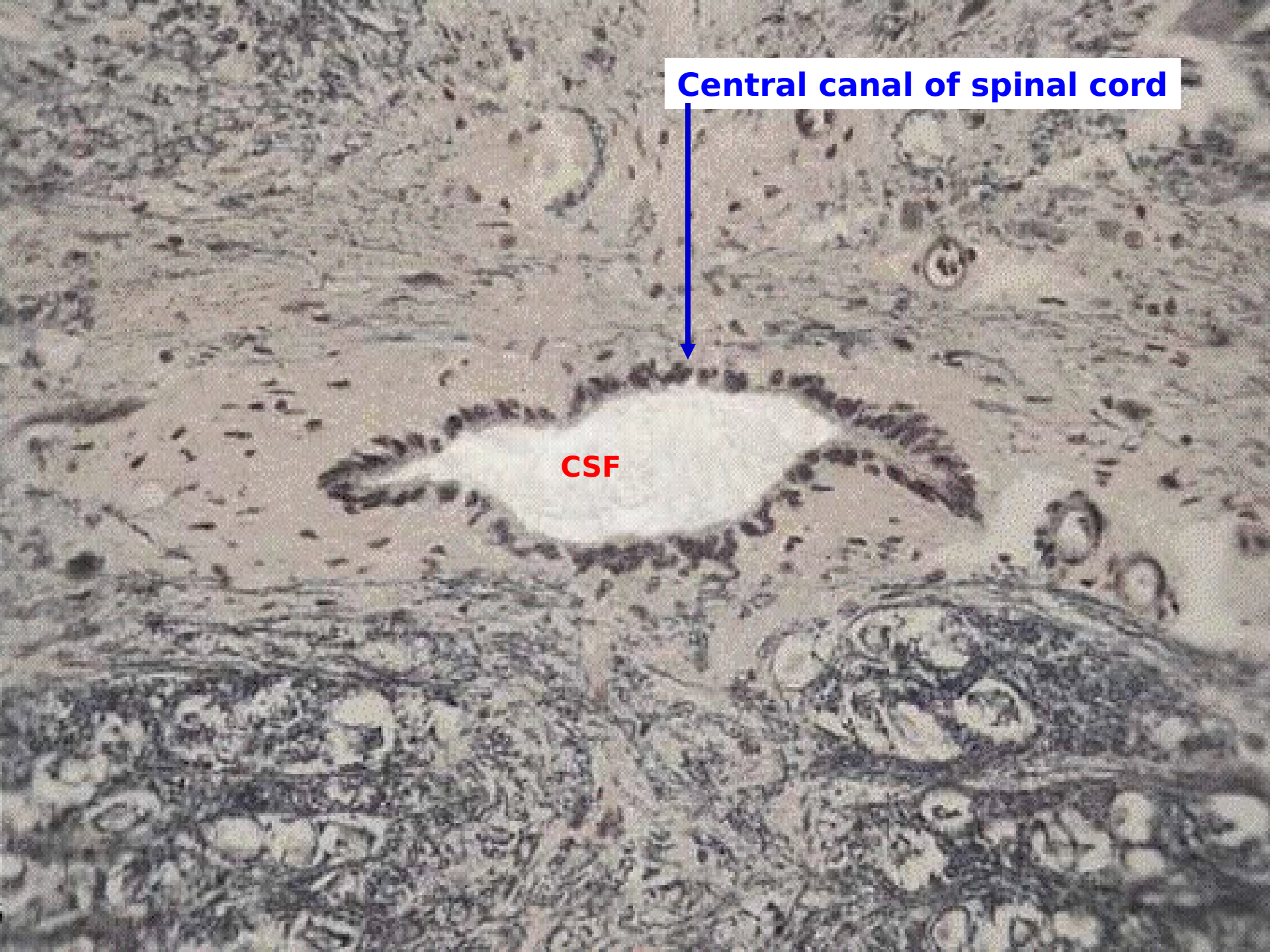
Gray matter



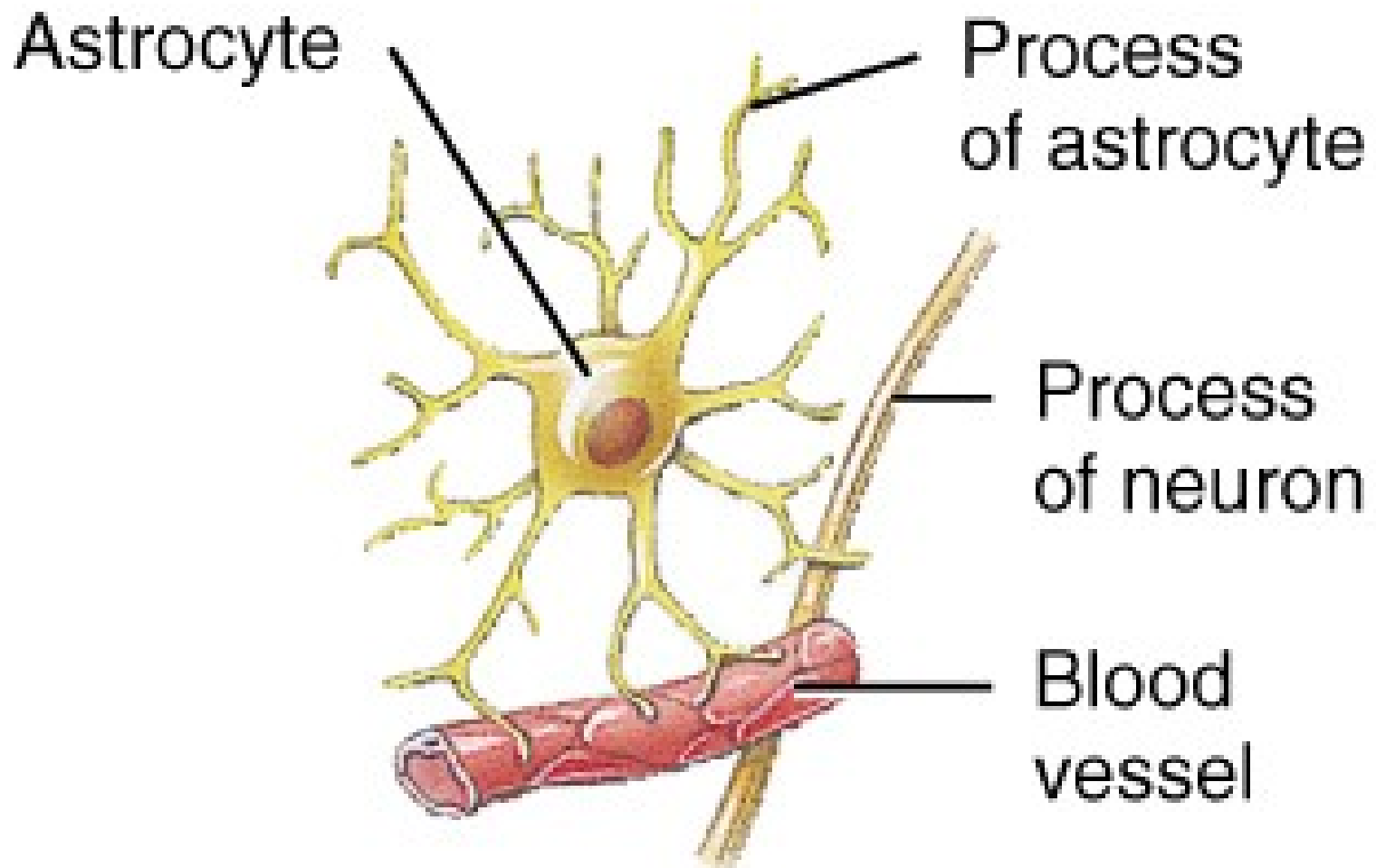
**Central canal of spinal cord**



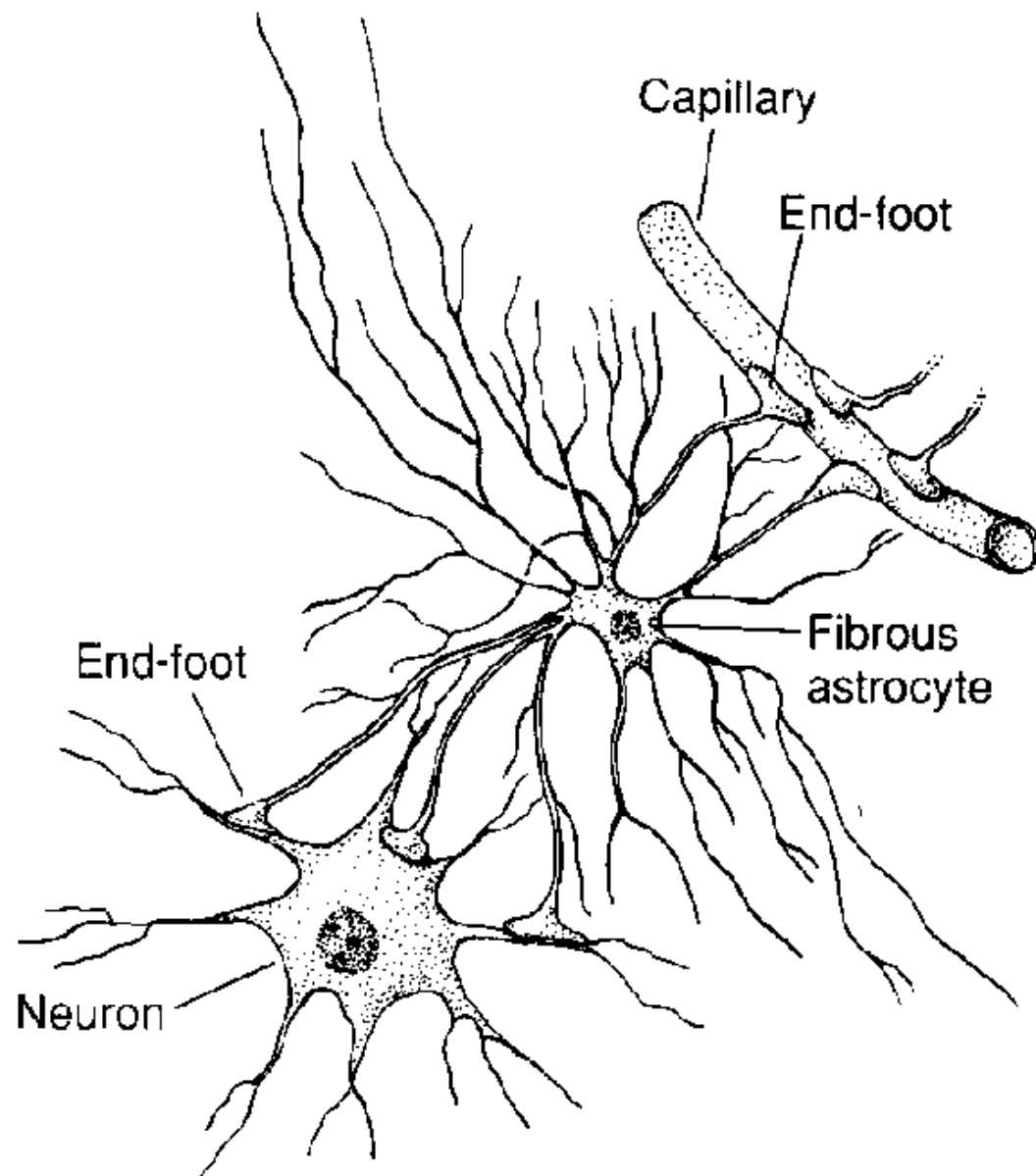
**CSF**



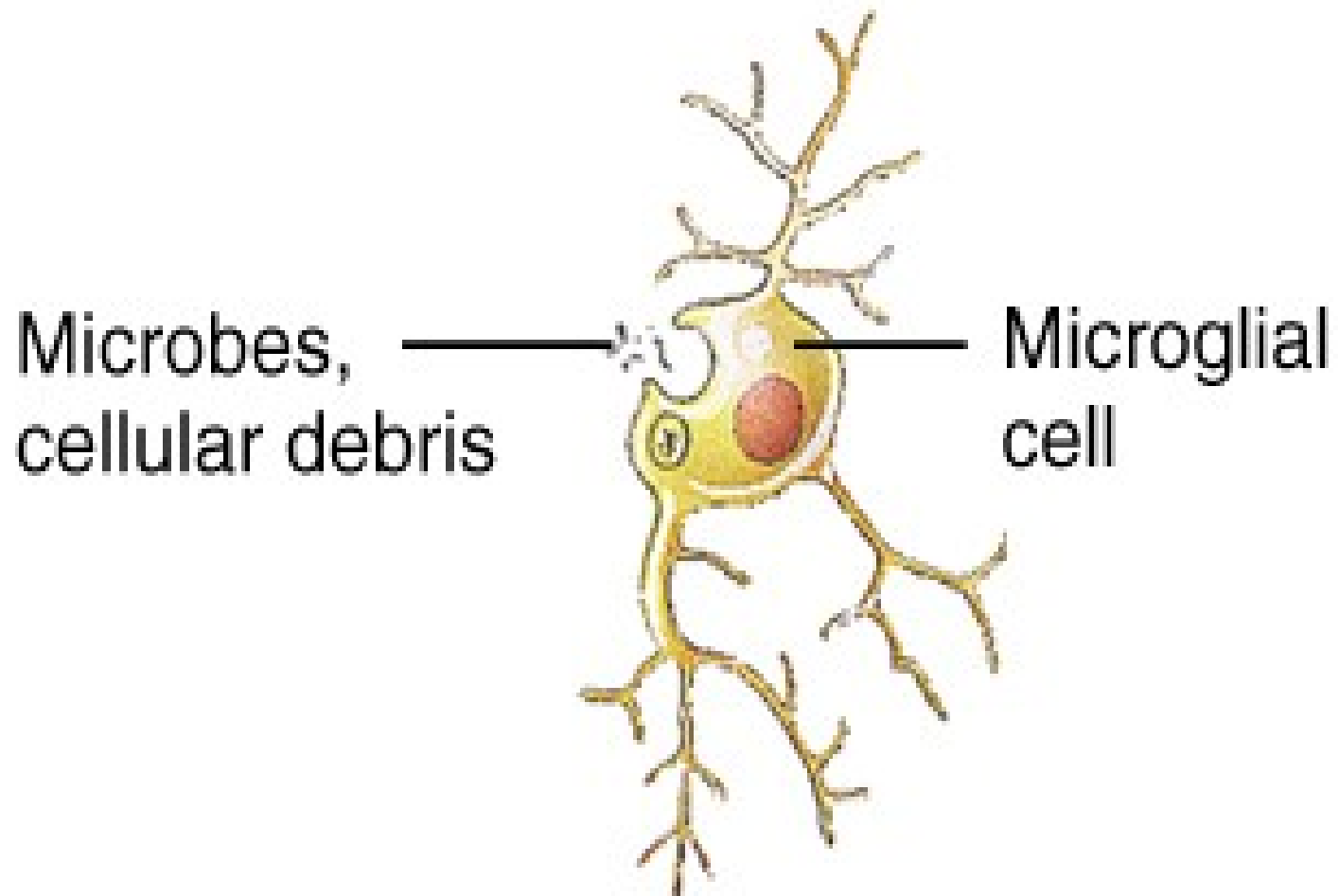
# ASTROCYTES



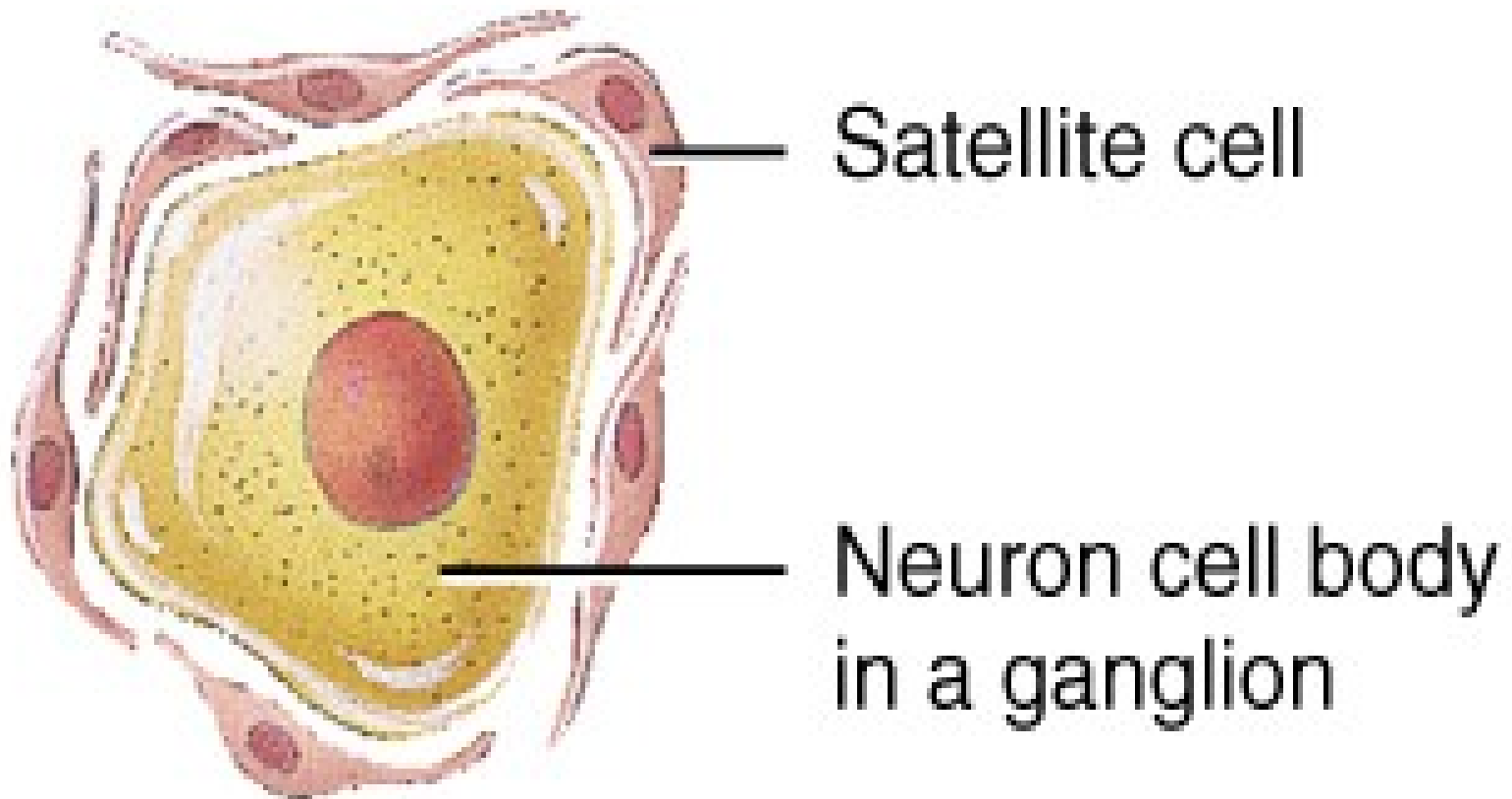
# Astrocyte

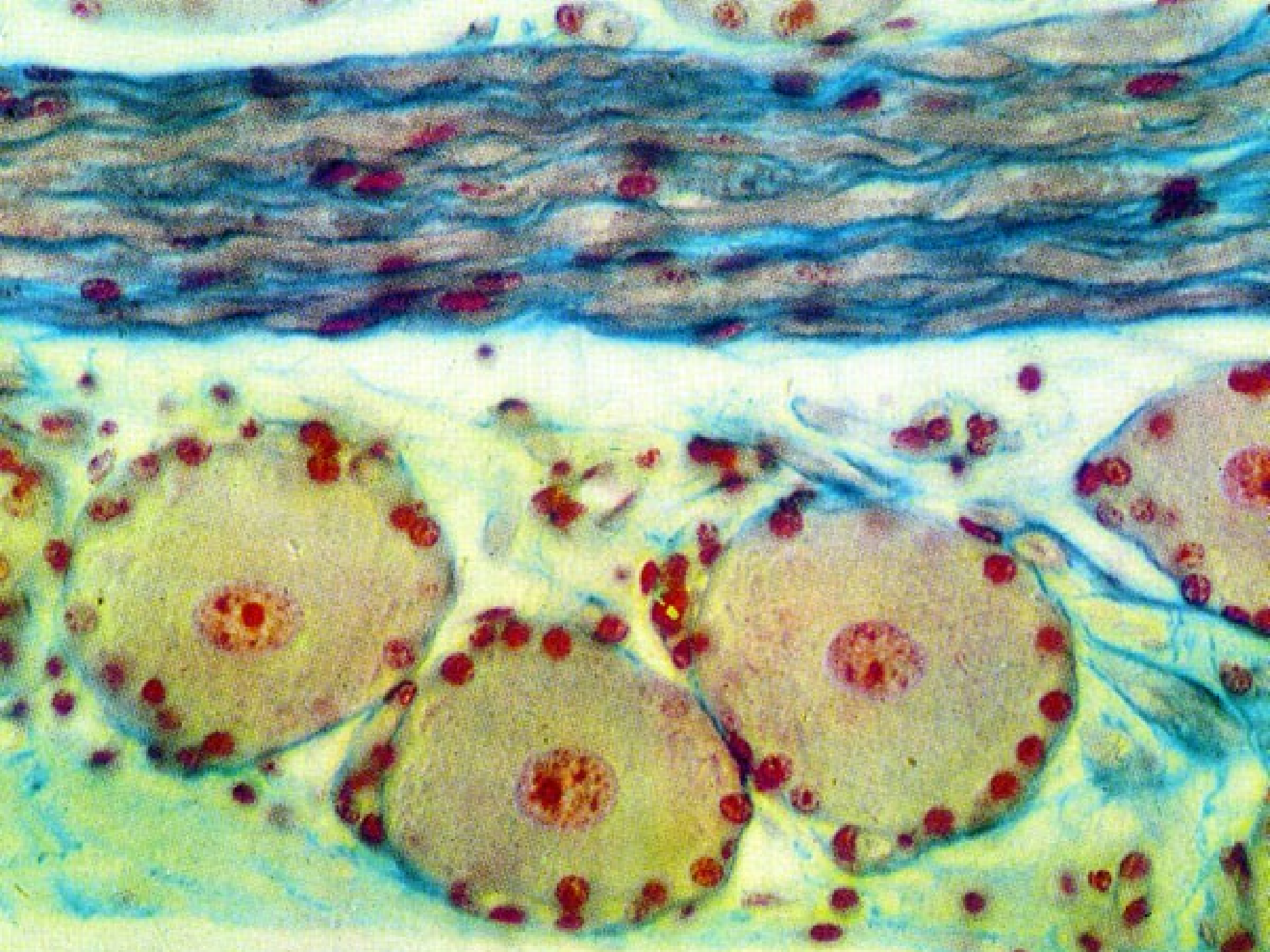


# MICROGLIAL CELLS



# SATELLITE CELLS





**BREAK TIME**

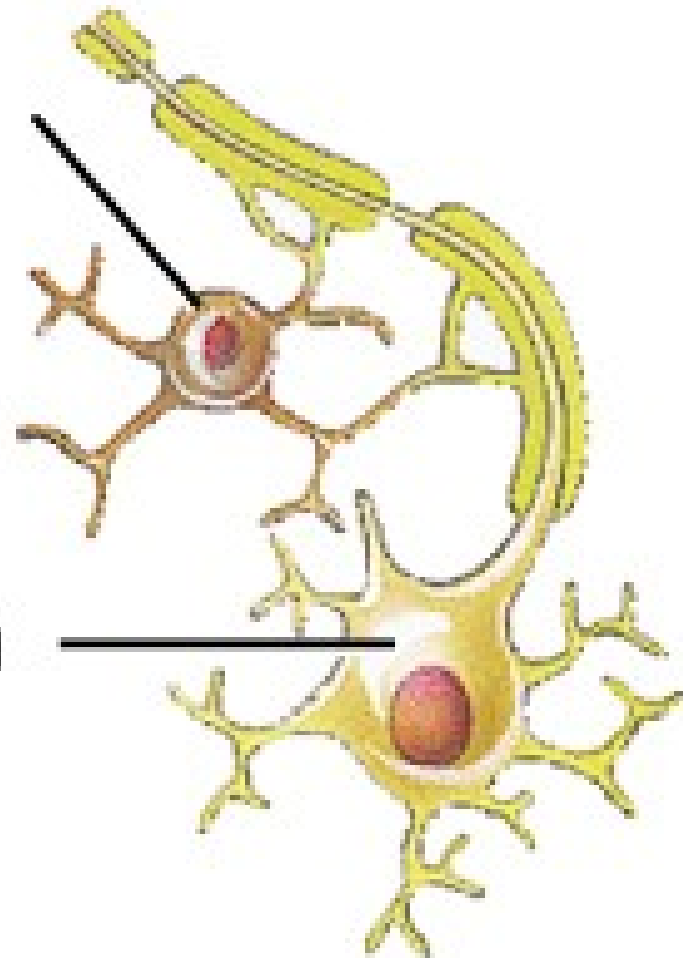
# OLIGODENDROCYTES & SCHWANN CELLS

- Responsible for myelinating axons
  - **Myelination** = insulation
- **Oligodendrocytes** myelinate **CNS**
- **Schwann cells** myelinate **PNS**

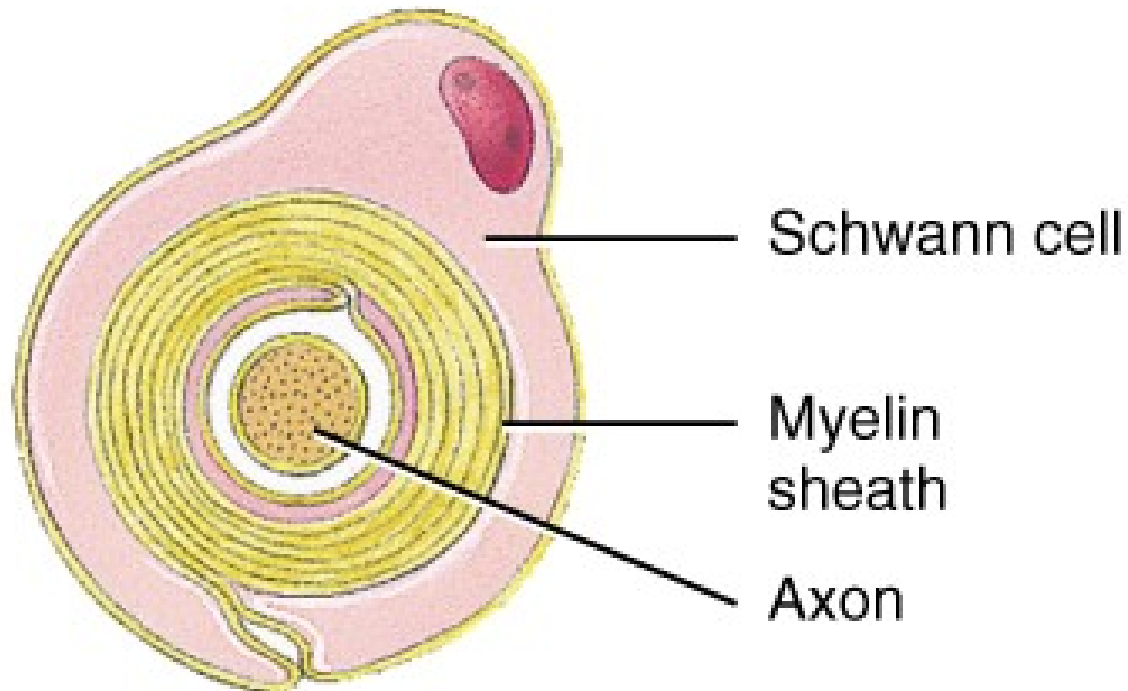
# OLIGODENDROCYTES

Oligodendrocyte

Neuron



# SCHWANN CELLS

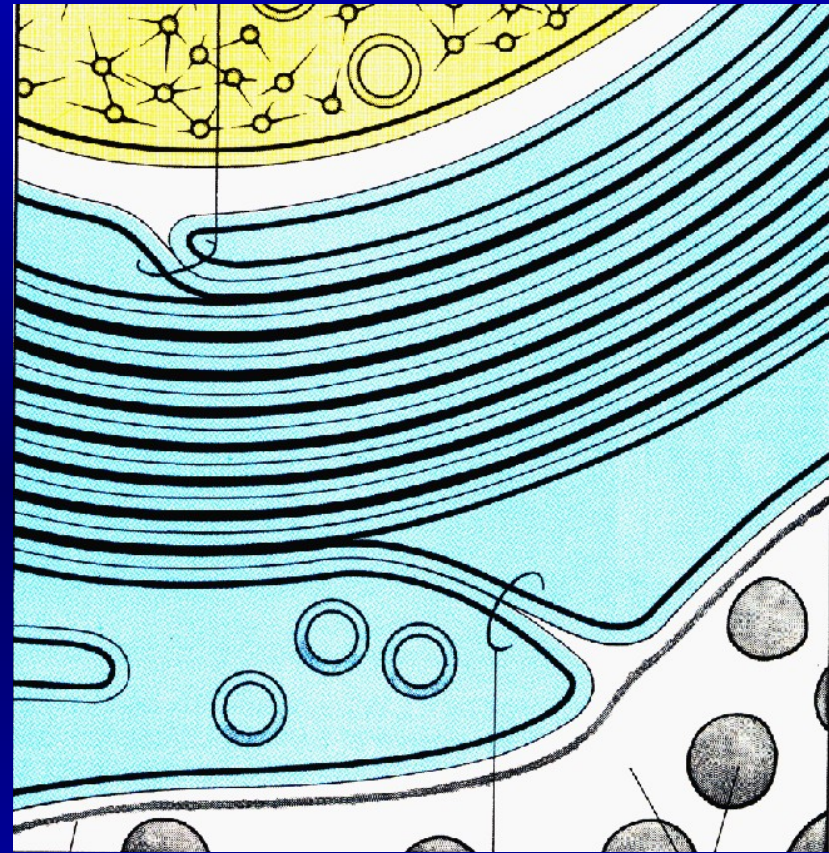
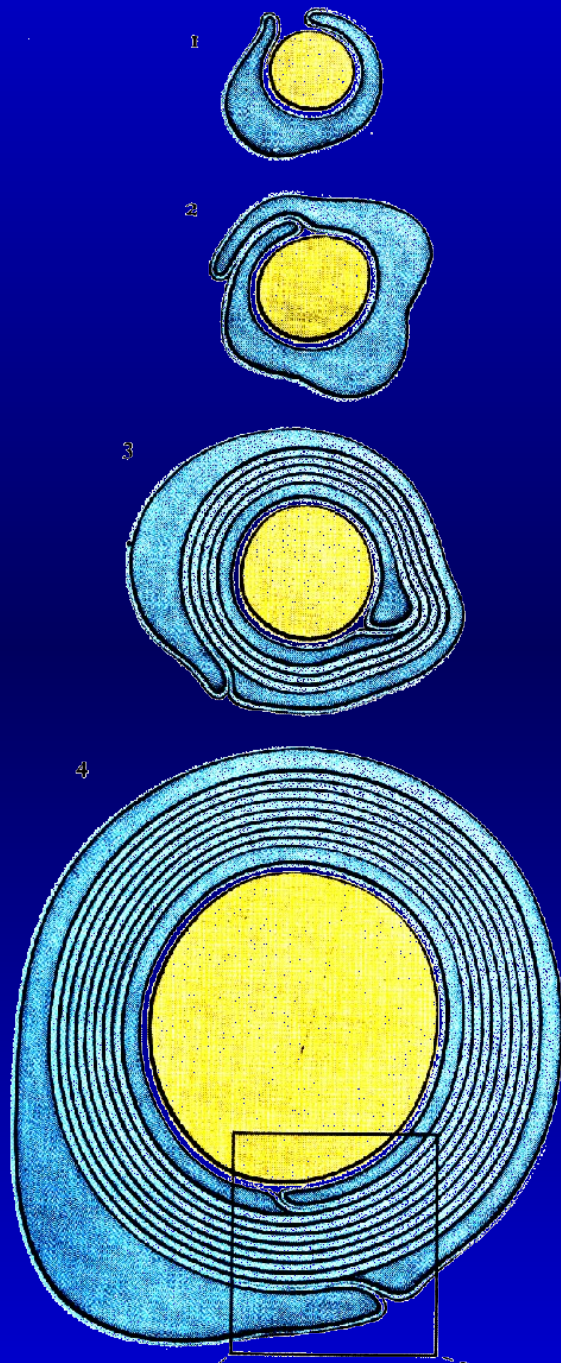


# MYELINATION

- Insulate axons
- 1 axon insulated by many **Schwann cells**
  - Cells divide and migrate
- 1 **Oligodendrocyte** insulates many axons
- Facilitates conduction (speed)
- **Nodes of Ranvier**
  - Spaces or “gaps” in the myelin
  - Sites of saltatory conduction

# MYELINATION

- A multilayered lipid and protein covering called the *myelin sheath* and produced by **Schwann cells** (PNS) and **oligodendrocytes** (CNS) surrounds the axons of most neurons.
- The sheath electrically insulates the axon and increases the speed of nerve impulse conduction.
- Schwann cells produce the myelin sheath in the **PNS**.

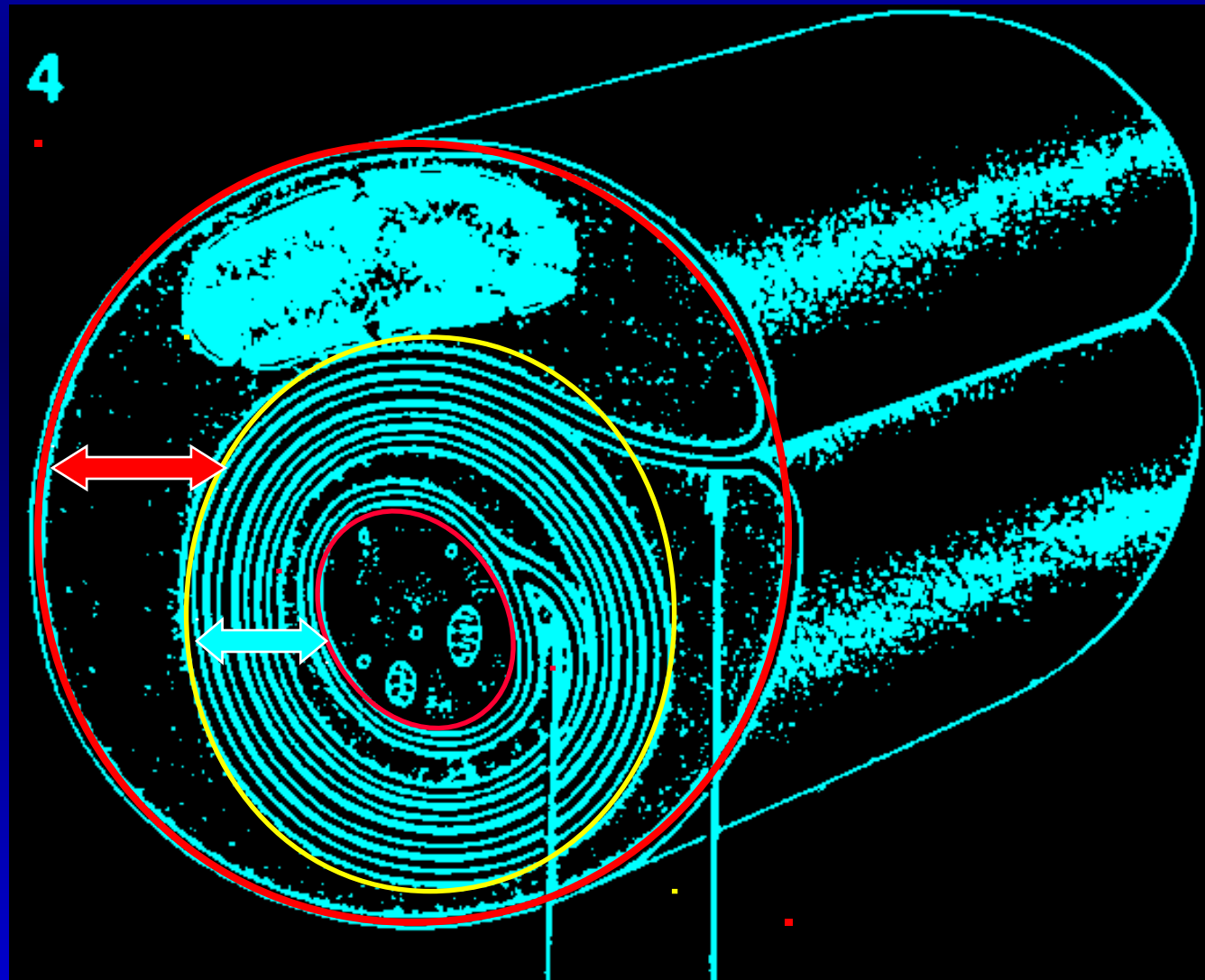


# MYELINATION

- The outer nucleated cytoplasmic layer of the Schwann cell, which encloses the myelin sheath, is called the *neurolemma* (*sheath of Schwann*) and is found **only** around axons in the **PNS**.
- The **neurolemma aids in regeneration** in an injured axon by forming a regeneration tube that guides and stimulates regrowth of the axon.

# NEURILEMMA

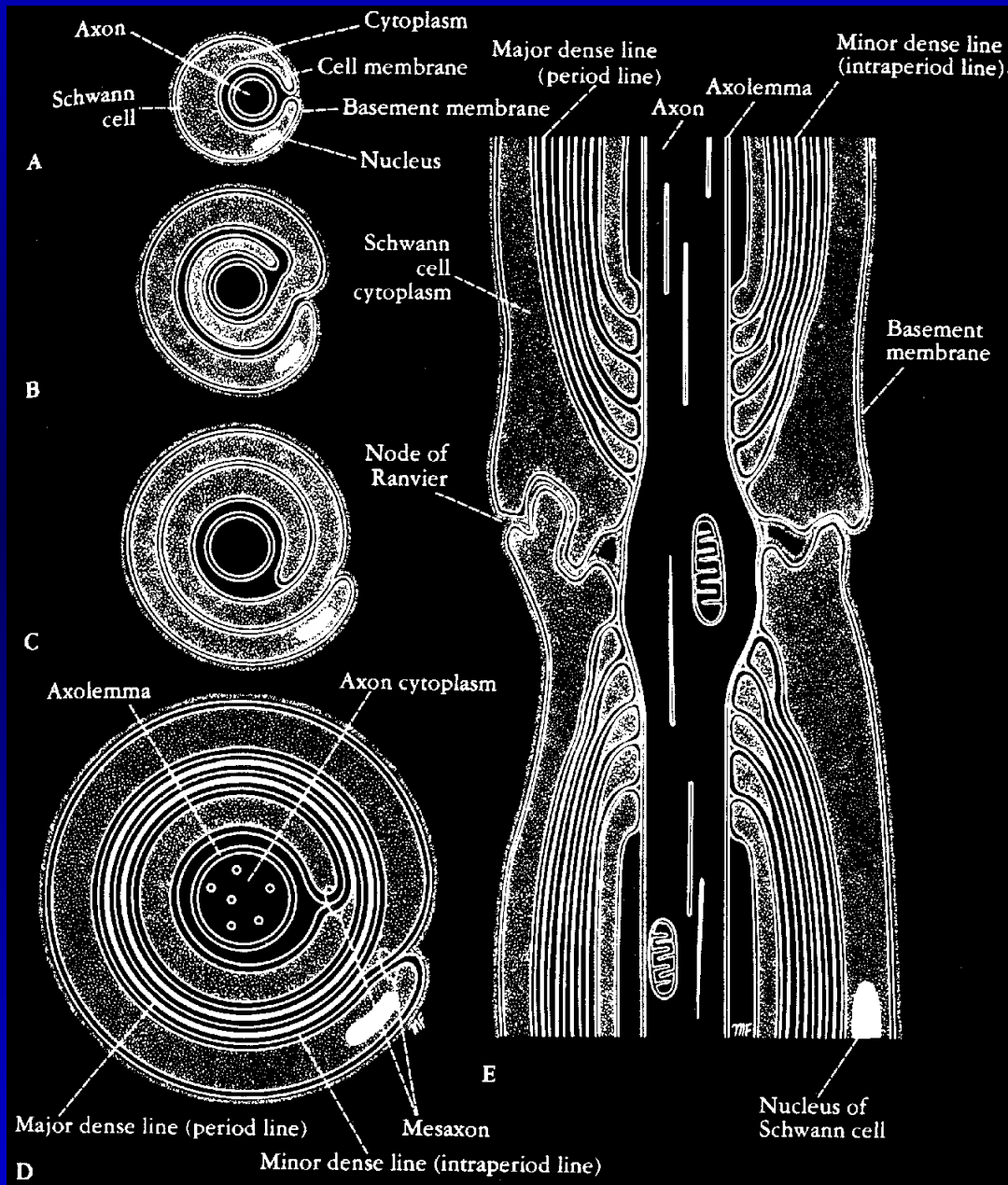
- Axolemma
- Myelin
- Neurilemma



# MYELINATION

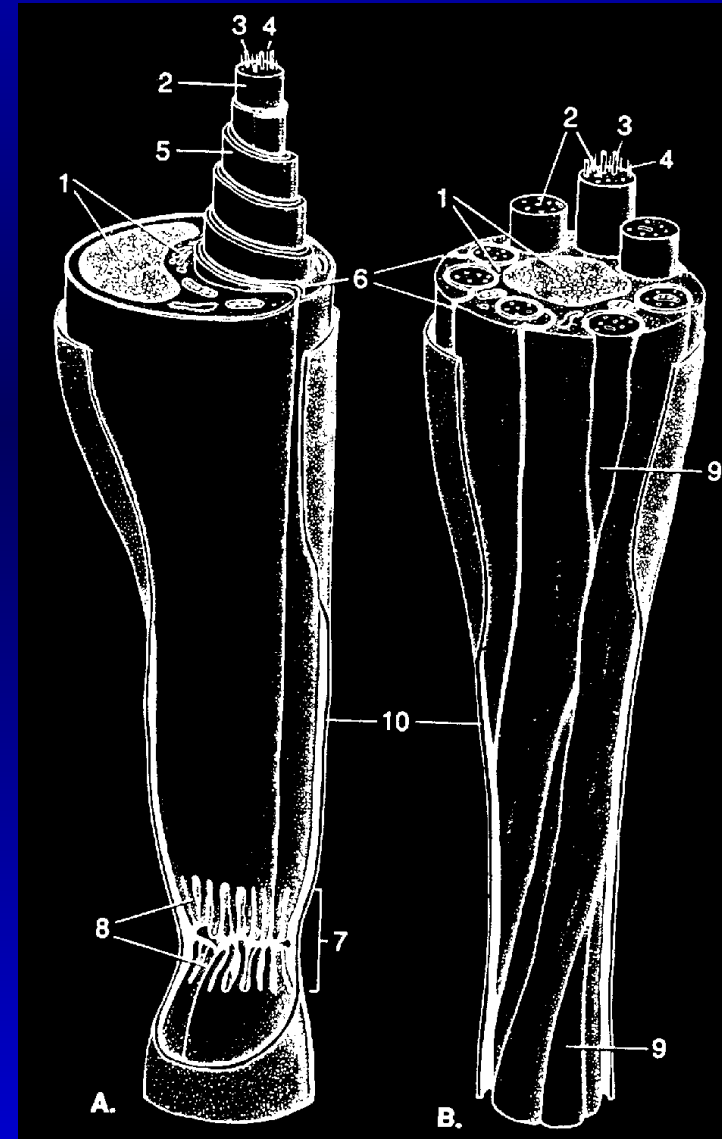
- The myelin sheath has gaps called ***neurofibril nodes*** or ***nodes of Ranvier*** along the axon.

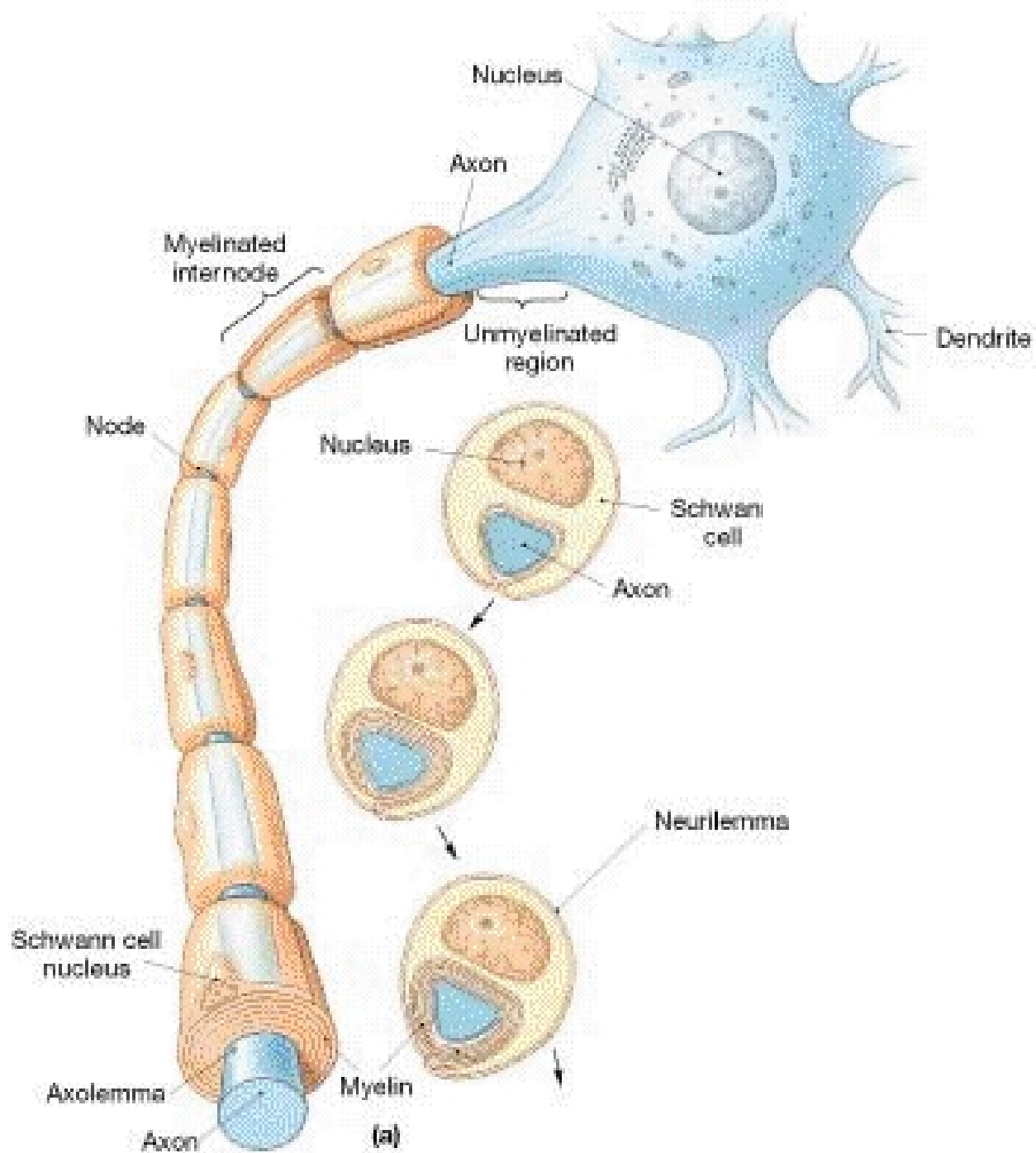
# Node of Ranvier



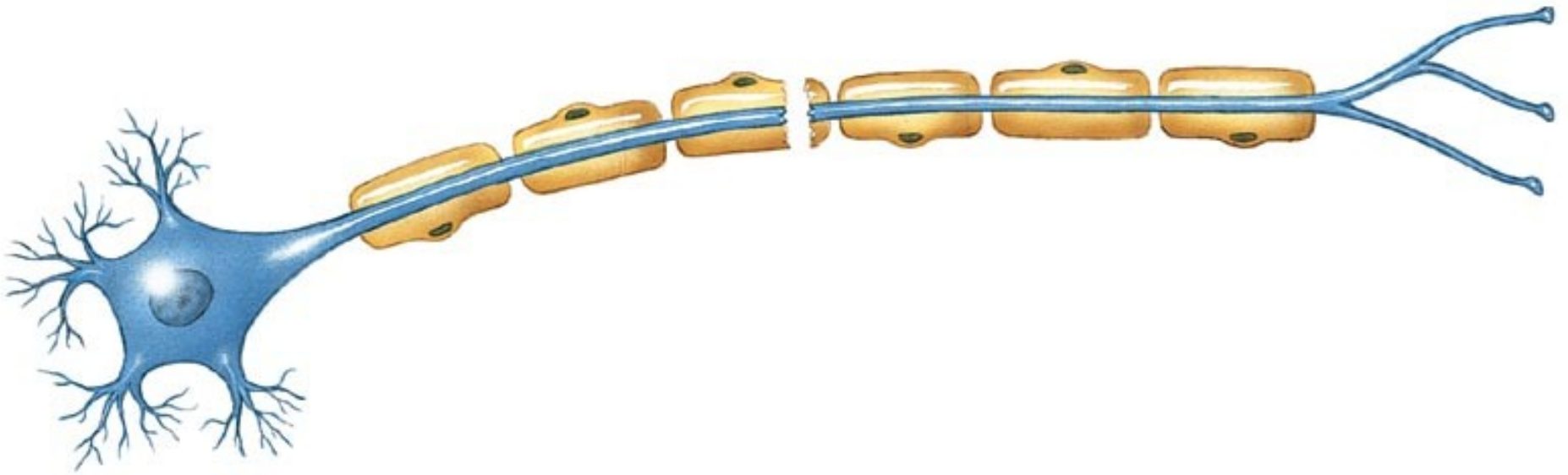
# Myelinated vs Unmyelinated

- **Unmyelinated**
  - Just no myelin - Schwann cell still there
  - smaller axons
  - more axons per Schwann cell





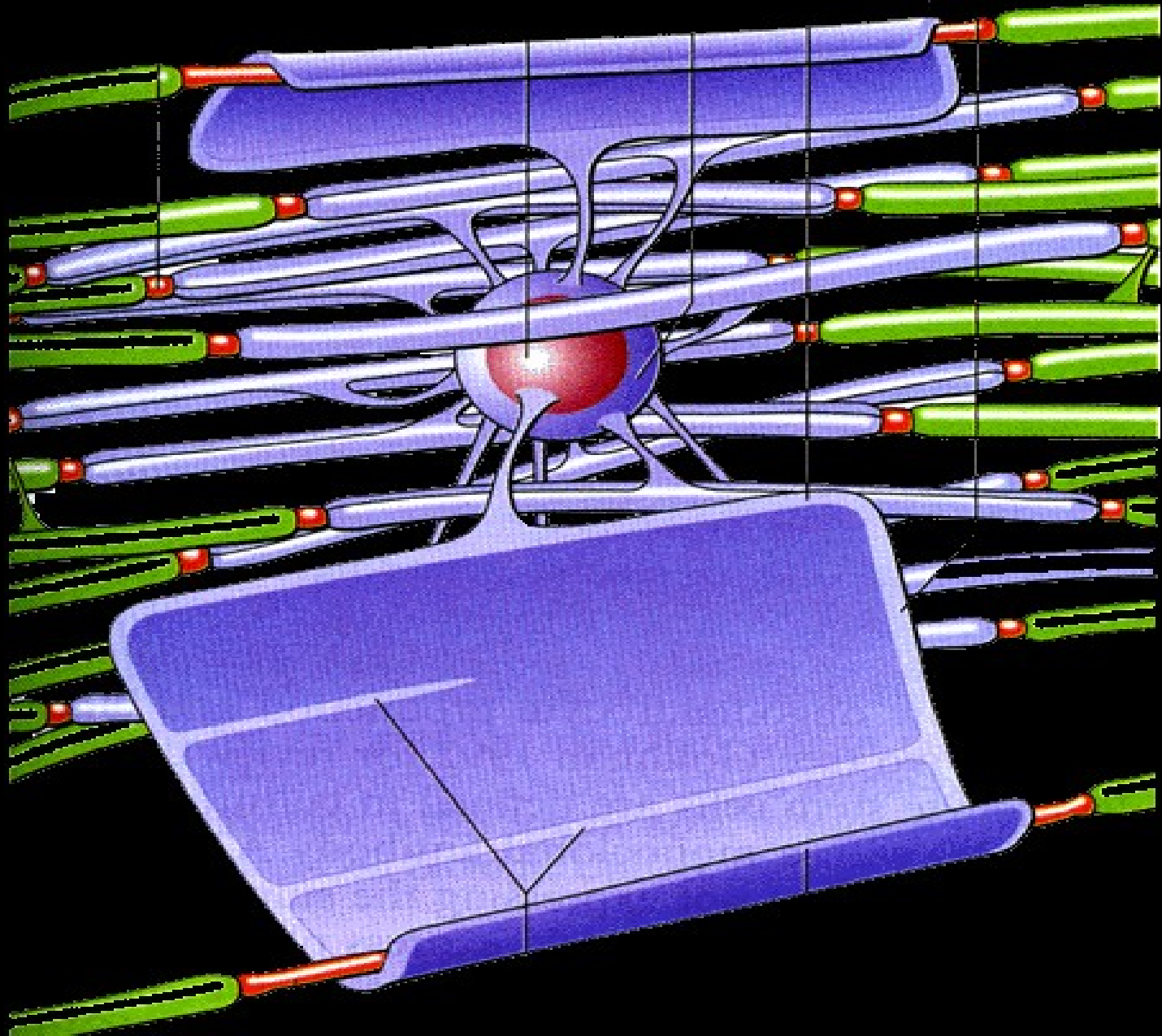
# Myelinated

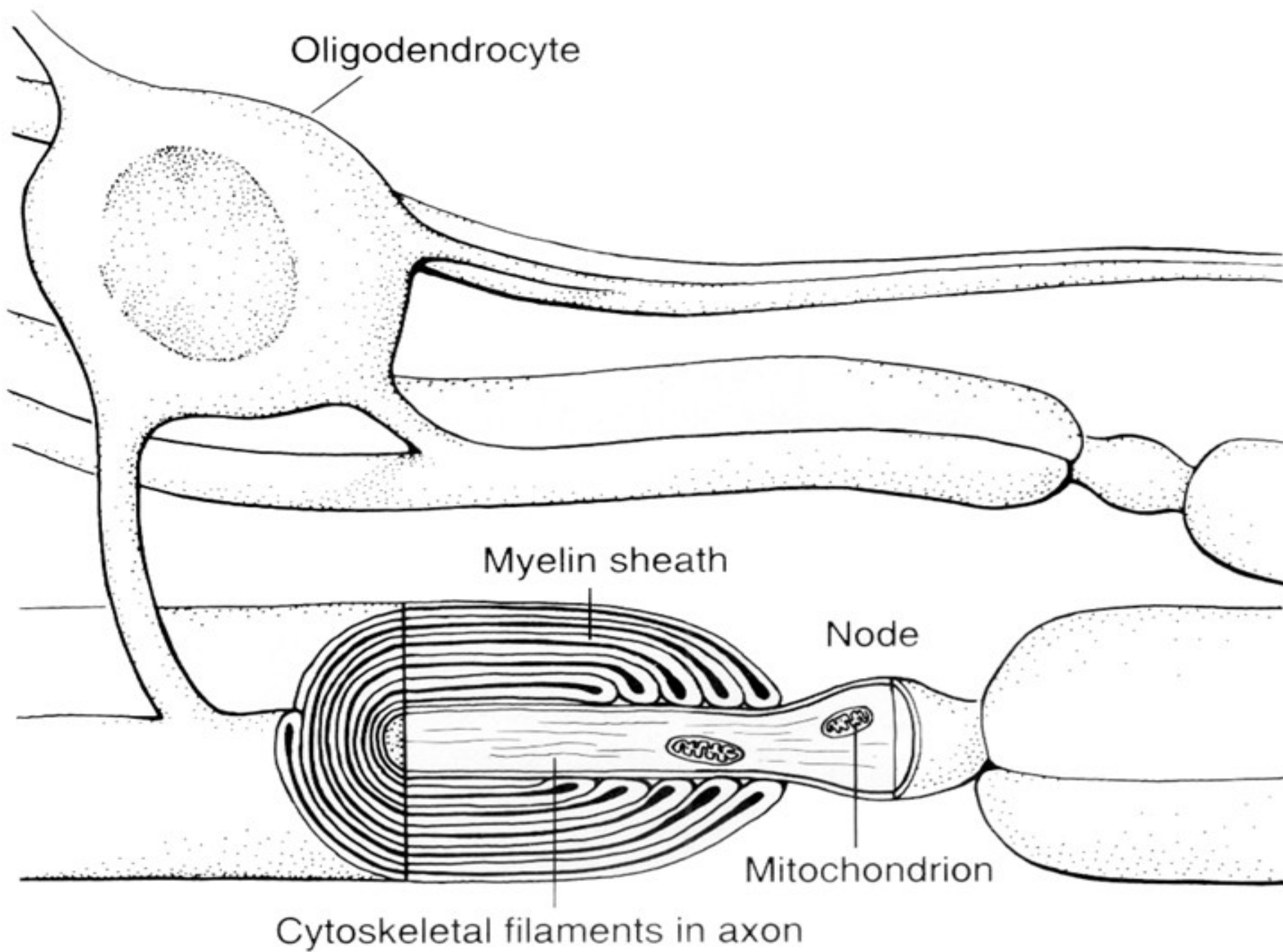


# Oligodendrocytes

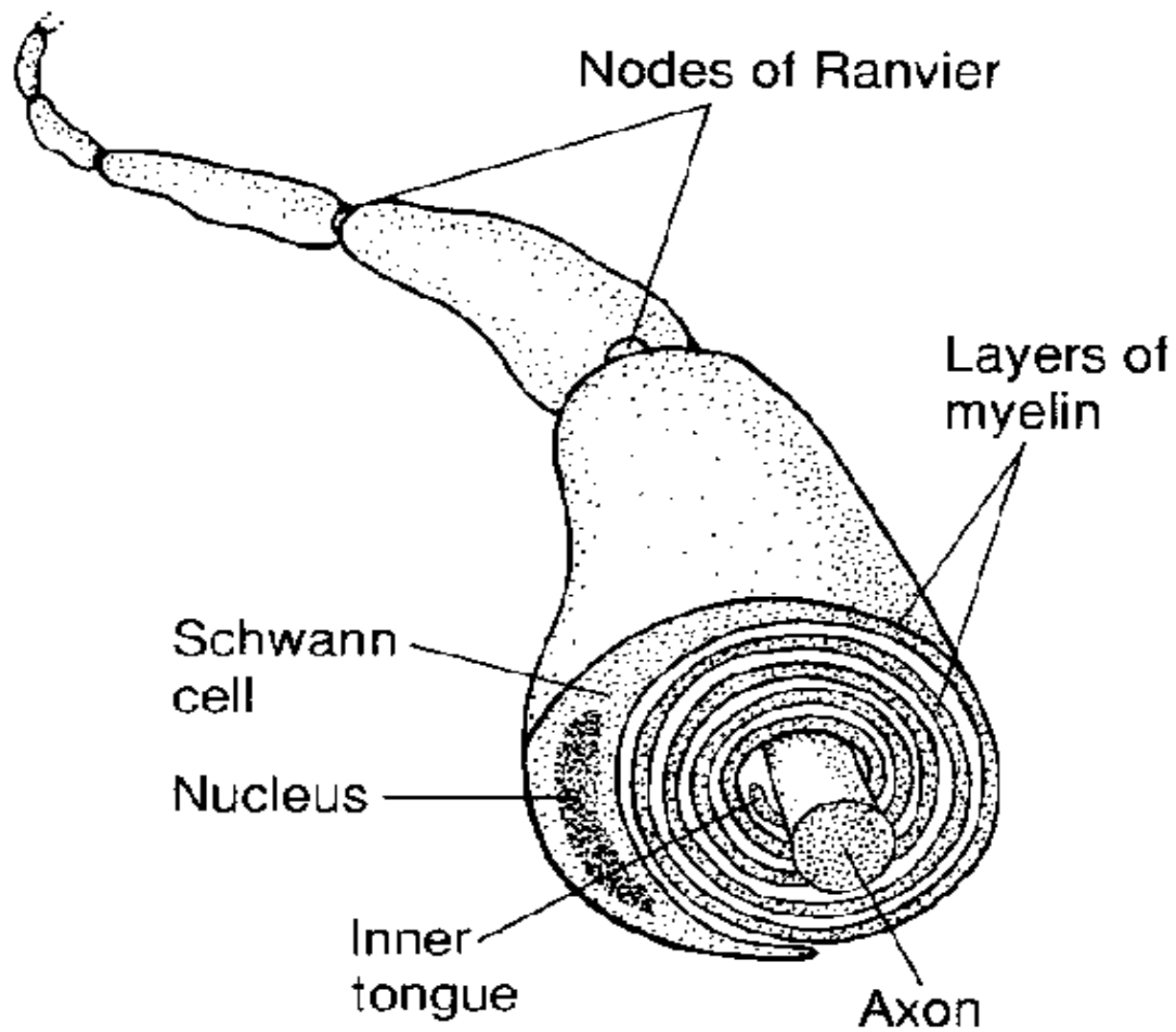
- Oligodendrocytes form myelin sheaths for **CNS** axons
- No **neurolemma** is formed.
- No **regrowth** after injury occurs.

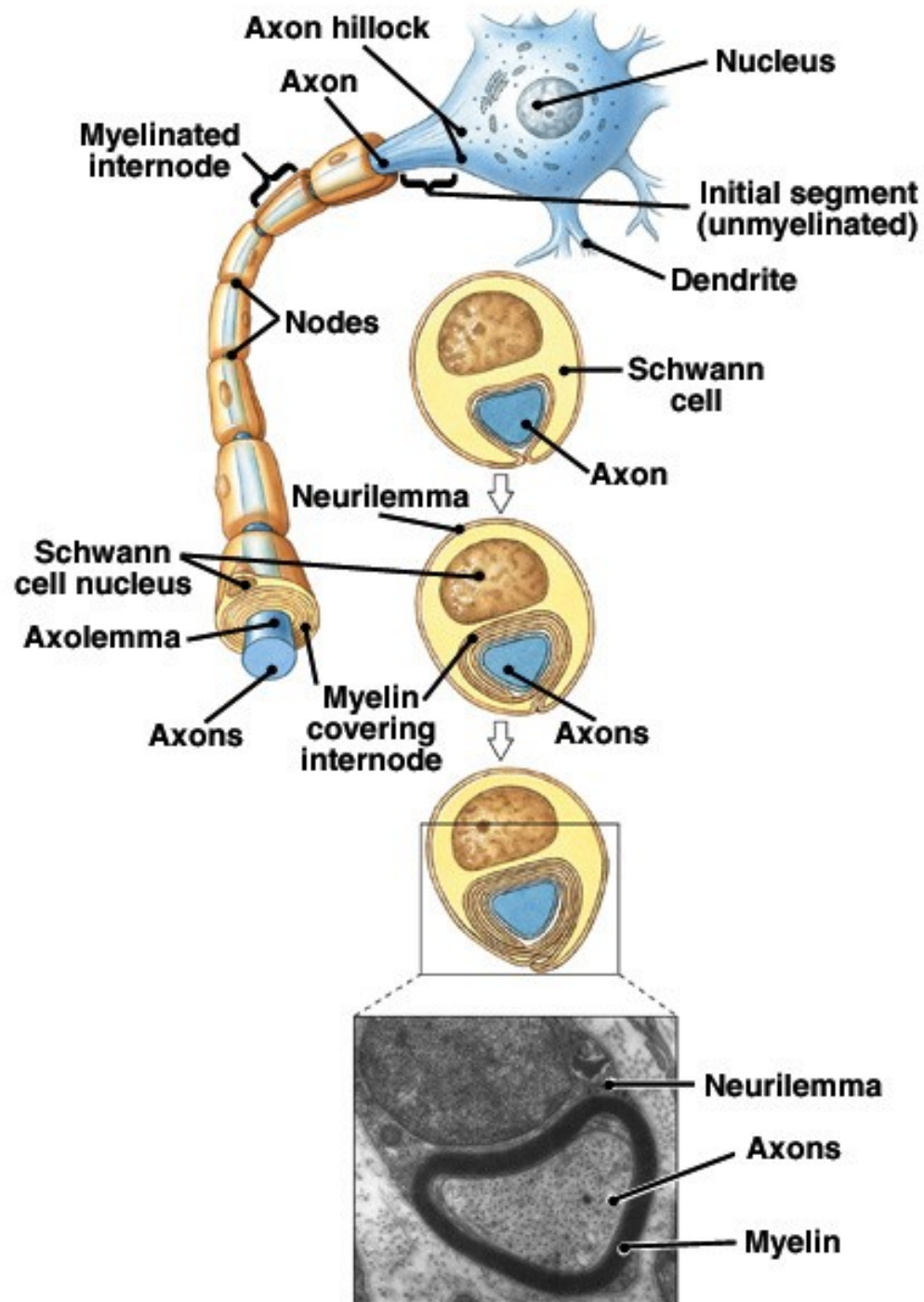
# Oligodendrocyte

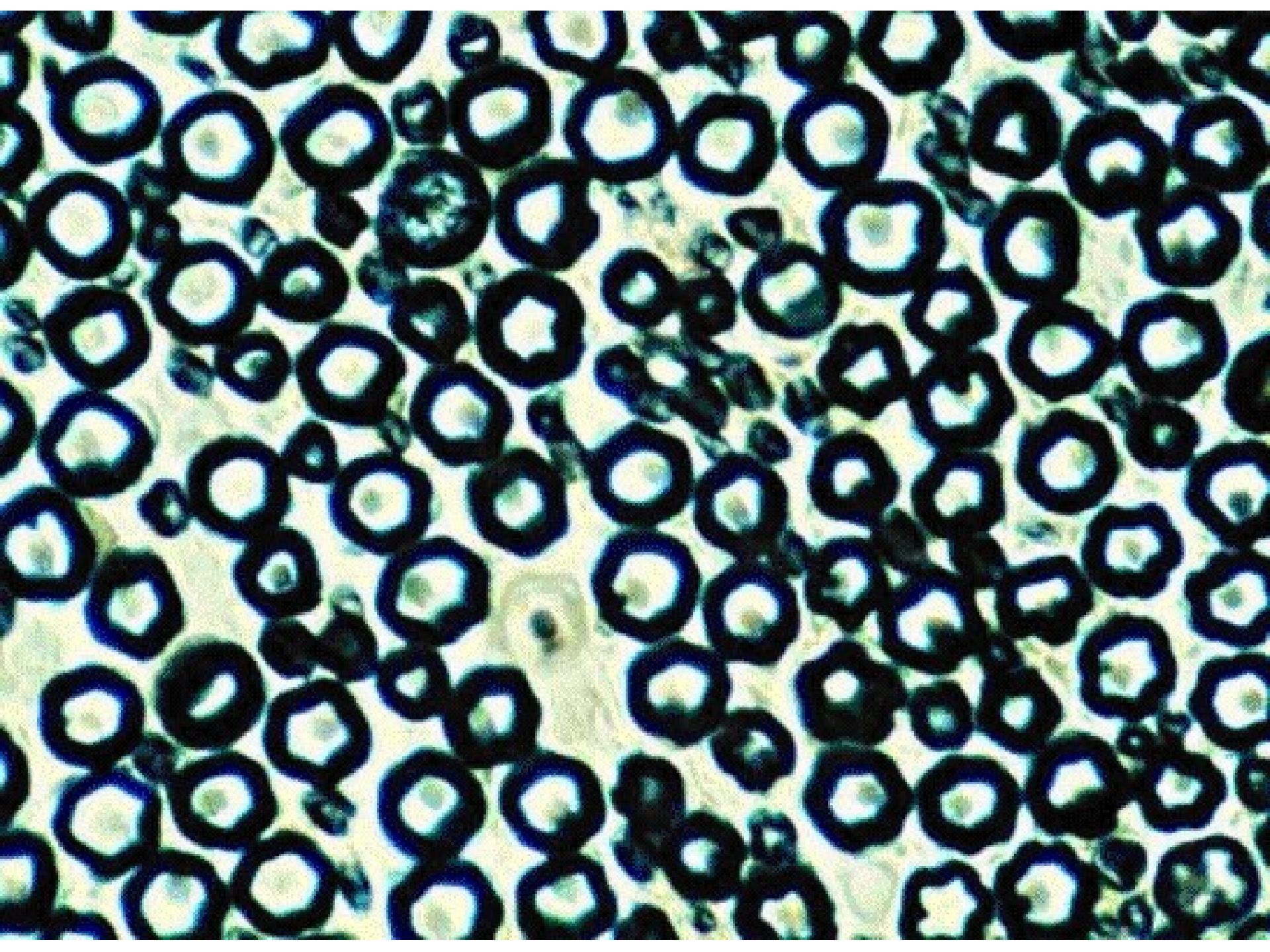




# Schwann cell



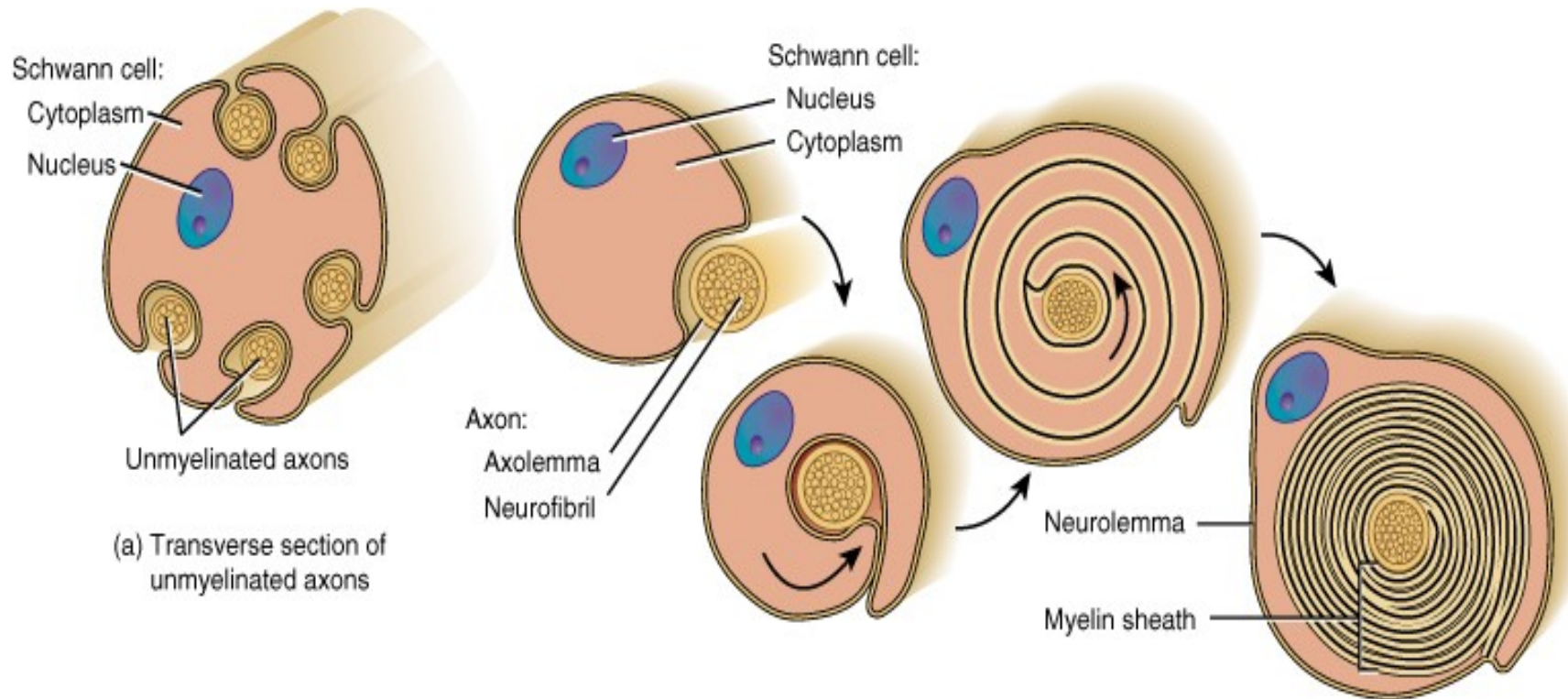




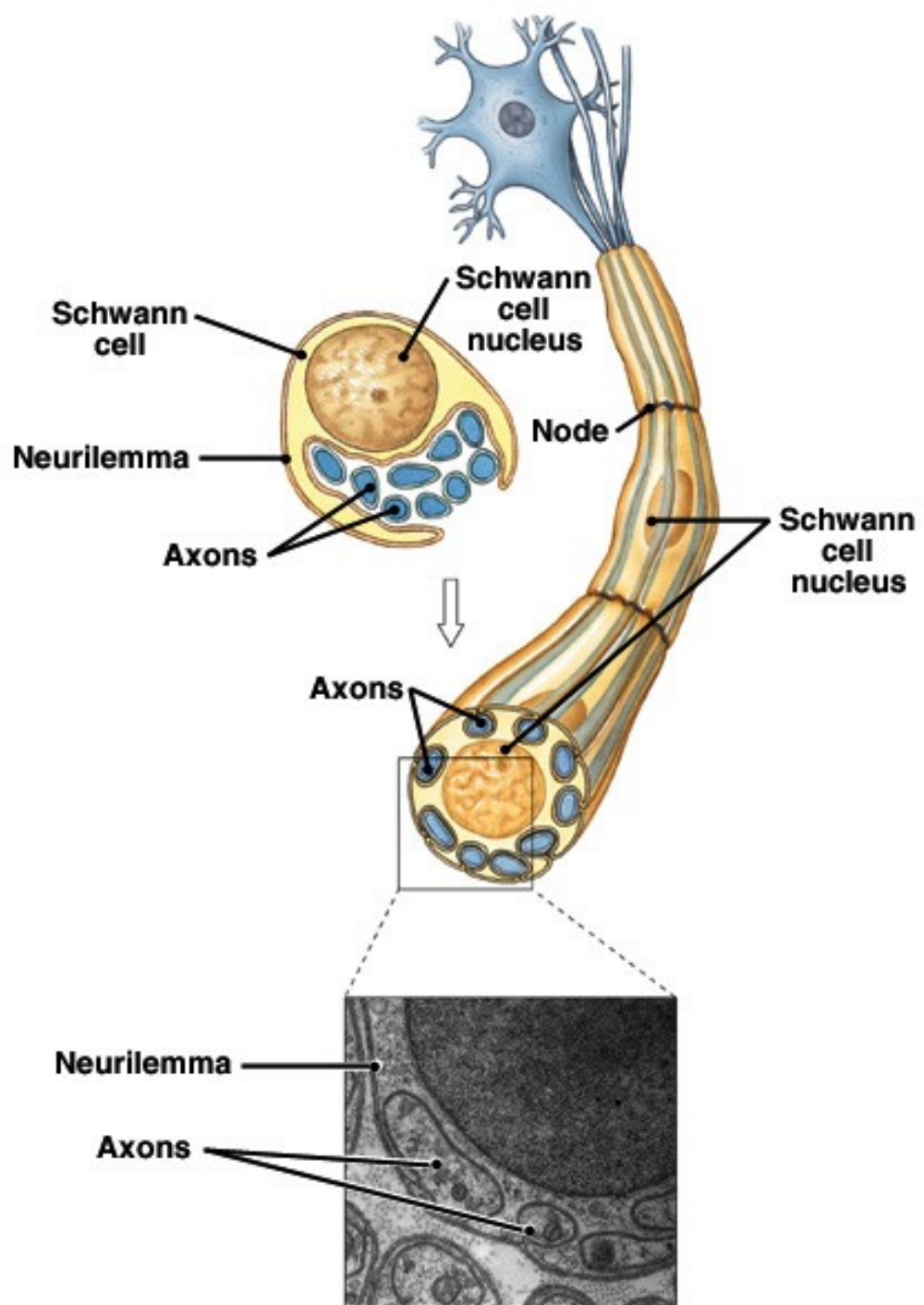
# SIZE (DIAMETER)

- Class A fibers
  - Myelinated
  - Fast
- Class B fibers
  - “Intermediate”
- Class C fibers
  - Unmyelinated
  - Slow

# UNMYELINATED AXONS



(b) Transverse sections of stages in the formation of a myelin sheath



# NEURONS

- Neurons have the property of **electrical excitability**.
- Most *neurons*, or nerve cells, consist of a cell body (soma), many dendrites, and usually a single axon.
- The *cell body* contains a nucleus, lysosomes, mitochondria, a Golgi complex, cytoplasmic inclusions such as lipofuscin, chromatophilic substances, and **neurofibrils**.

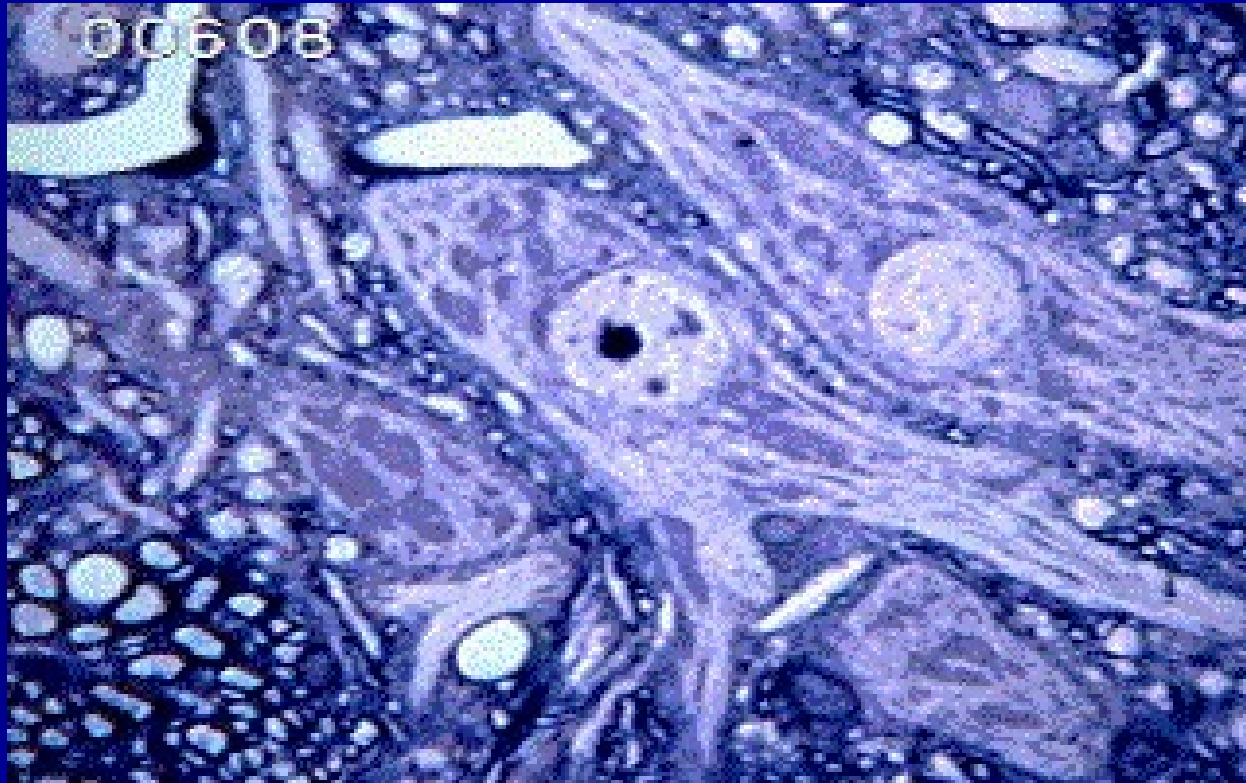
# NEURONS

- A common synonym for cell body is **soma** (pl. somata).
- Even though you can't see them without an electron microscope, neurons have all the other common "cytoplasmic inclusions", meaning stuff in the cytoplasm, as other cells including:
  - **Mitochondria** – lots
  - **Rough and Smooth Endoplasmic Reticulum** – lots
  - **Golgi Apparatus** the make vescicles contain the neurotransmitters that neurons secret.

# NEURONS - Nissl bodies

- **Chromatophilic** substances (**Nissl bodies**) are an orderly arrangement of rough ER.

# NEURONS - Nissl bodies



# NEURONS - Nissl bodies

- The RNA stain that is used in this picture is called a Nissl stain, named after the neuroscientist Franz Nissl who lived in the middle 1800s.
- **Nissl bodies**, or Nissl substance, are really just large clumps of rough ER that are clearly visible with a light microscope, well, if stained with the.... Nissl stain.

# NEURONS - Nissl bodies

- This is common for cells which are secretory cells and, as we will see neurons secrete chemicals called **neurotransmitters**.
- To make these chemicals requires lots of enzymes (proteins).

# NEUROFIBRILS

- **Neurofibrils** are subdivided into several classes based on size and shape -- the neurotubules (tubelike), **neurofilaments** (thin fibers), microfilaments (really thin fibers).
- These fibers play an important role in moving all those protein molecules from the **ER** of the soma all the way down to the ends of the axons.

# NEUROFIBRILS

- **Neurofibrils** – are filaments found in neurons; not necessarily **neurofilaments** in all cases, and in the older literature 'fibrils' are composed of both microtubules and neurofilaments.
- **Neurofilament** – are member of the class of **intermediate filaments** found in axons of nerve cells consisting of three distinct protein subunits .

# NEUROFIBRILS

- This process is called **axoplasmic transport**.
- There is a lot known about how the various parts of the neurofibrils work to **move molecules**, but all I want you to know is that neurofibrils help to move molecules from one part of the neuron to another.

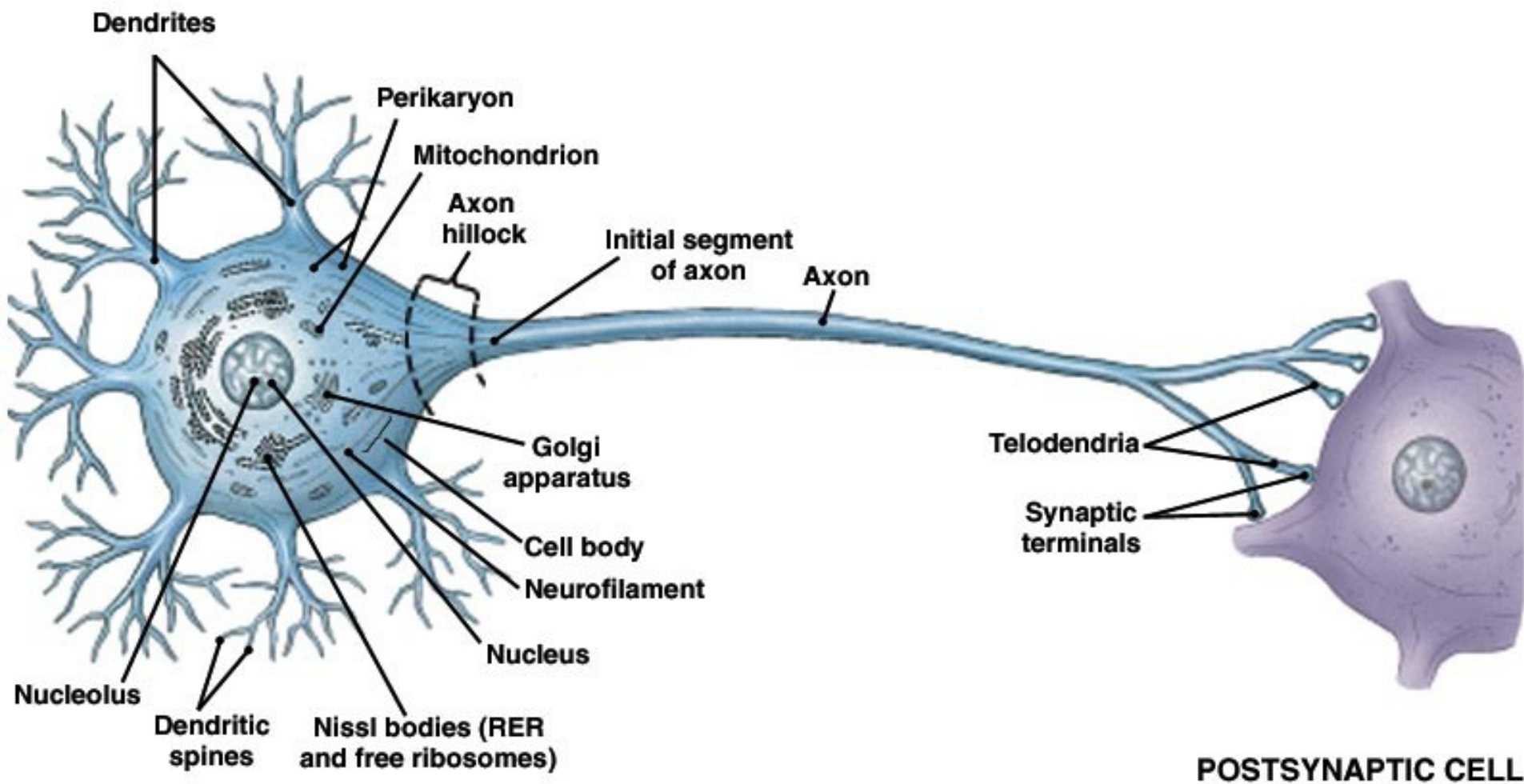
# NEURONAL TRANSPORT

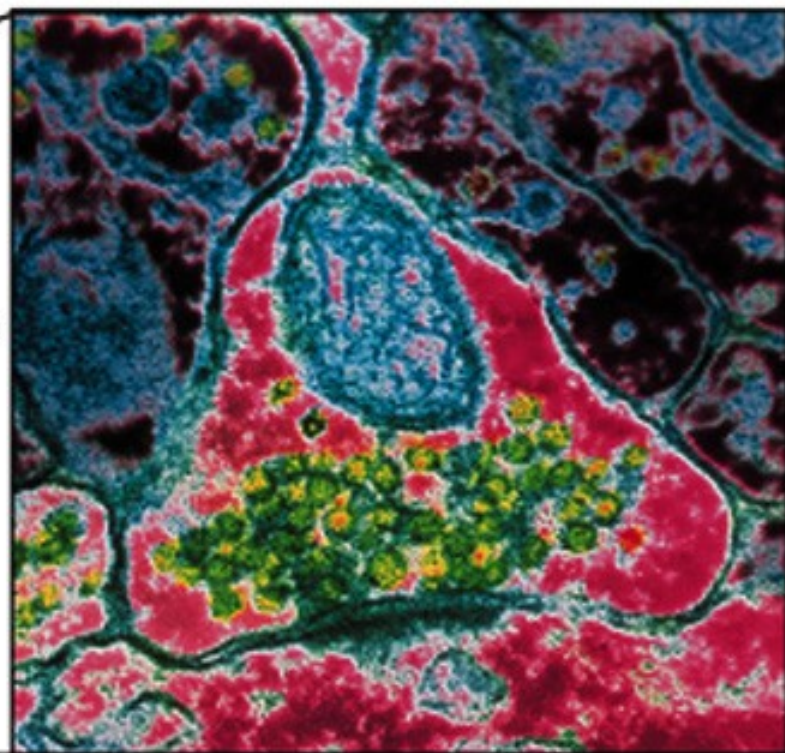
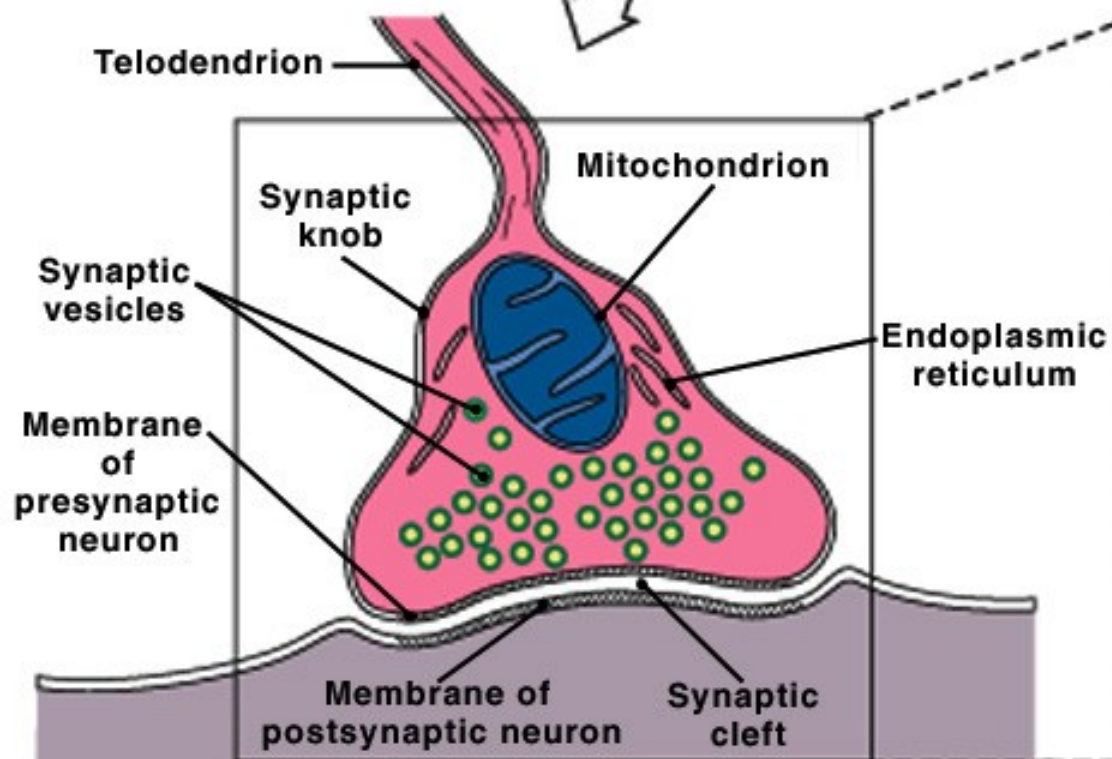
- ***Axonal transport***, a natural mechanism of intracellular transport in neurons, is exploited by certain microorganisms to reach other parts of the nervous system.
- ***Fast axonal transport*** is the route by which some toxins (such as toxins produced by bacteria) and disease causing viruses make their way from axon terminals near skin cuts to cell bodies, where they cause damage.

# NEURONS

- The ***dendrites*** conduct impulses from receptors or other neurons to the cell body.
- The ***axon*** conducts nerve impulses from the neuron to the dendrites or cell body of another neuron or to an effector organ of the body (muscle or gland).
- The site of functional contact between two neurons or between a neuron and an effector cell is called a ***synapse***.

## PRESYNAPTIC CELL



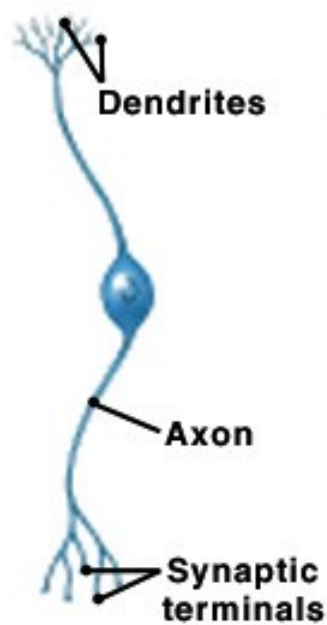


# Structural and Functional Variations in Neurons

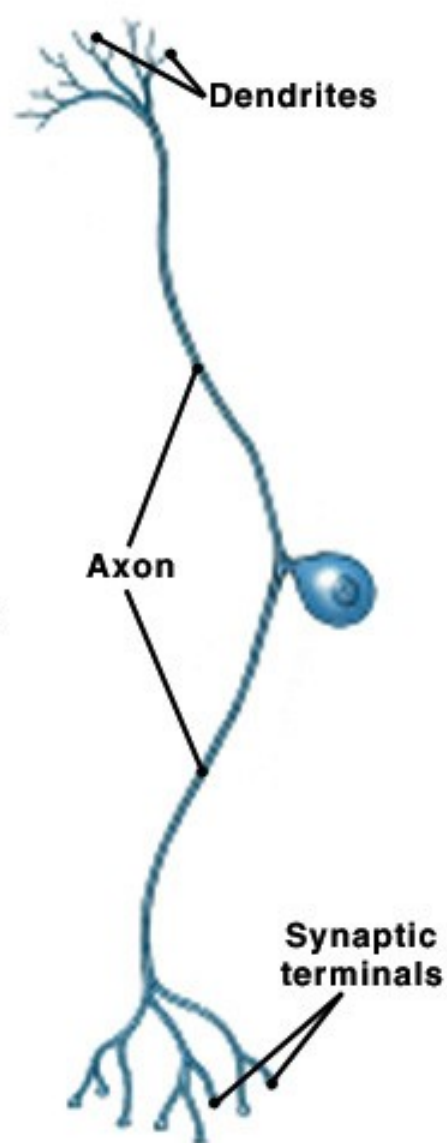
- Both structural and functional features are used to classify the various neurons in the body.
- On the basis of the **number of processes** extending from the cell body (structure), neurons are classified as:
  - *multipolar*,
  - **biopolar**, and
  - *unipolar*.



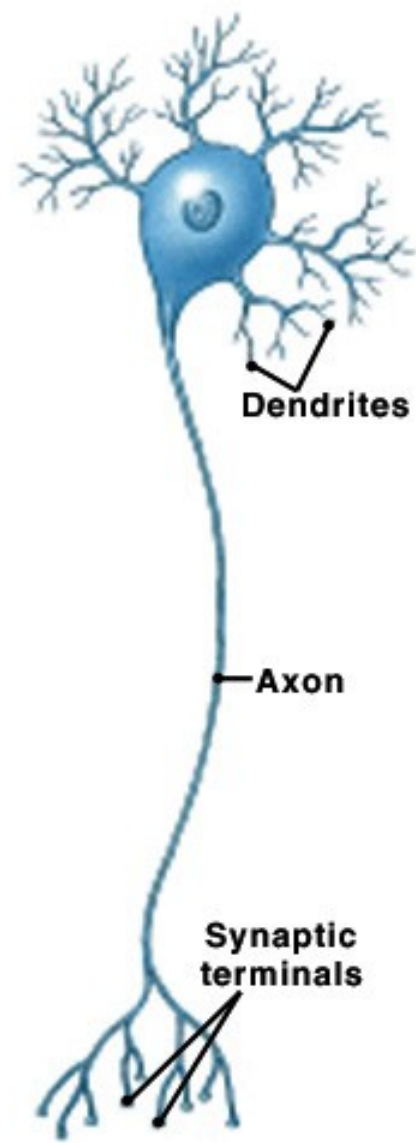
**(a) Anaxonic neuron**



**(b) Bipolar neuron**



**(c) Unipolar neuron**



**(d) Multipolar neuron**

# **Gray and White Matter**

# Gray and White Matter

- ***White matter*** is composed of aggregations of **myelinated processes** whereas,
- ***Gray matter*** contains **nerve cell bodies**, **dendrites**, and **axon terminals** or bundles of **unmyelinated axons** and **neuroglia**.

# Gray and White Matter

- In the spinal cord, gray matter forms an **H-shaped inner core**, surrounded by white matter;
- In the brain a thin outer shell of **gray matter** covers the cerebral hemispheres – **Neural Cortex**.

# **ACTION POTENTIALS**

# Electrical Signals In Neurons

- A **nucleus** is a mass of nerve cell bodies and dendrites inside the CNS.
- Excitable cells communicate with each other by ***action potentials*** or ***graded potentials***.
- ***Action potentials*** allow communication over short and long distances whereas ***graded potentials*** allow communication over short distances only!

# Electrical Signals In Neurons

- Production of both types of potentials depend upon the existence of a resting membrane potential and the presence of certain types of ion channels.

# Electrical Signals In Neurons

- The **membrane potential** is an **electrical voltage across the membrane**.
- **Graded** and **action** potentials occur because of **ion channels** in the membrane that allow ion movement across the membrane that can change the membrane potential.

# Ion Channels

- The two basic types of ion channels are **leakage** (**nongated**) and **gated**.
- **Leakage** (*nongated*) channels are always **open**.

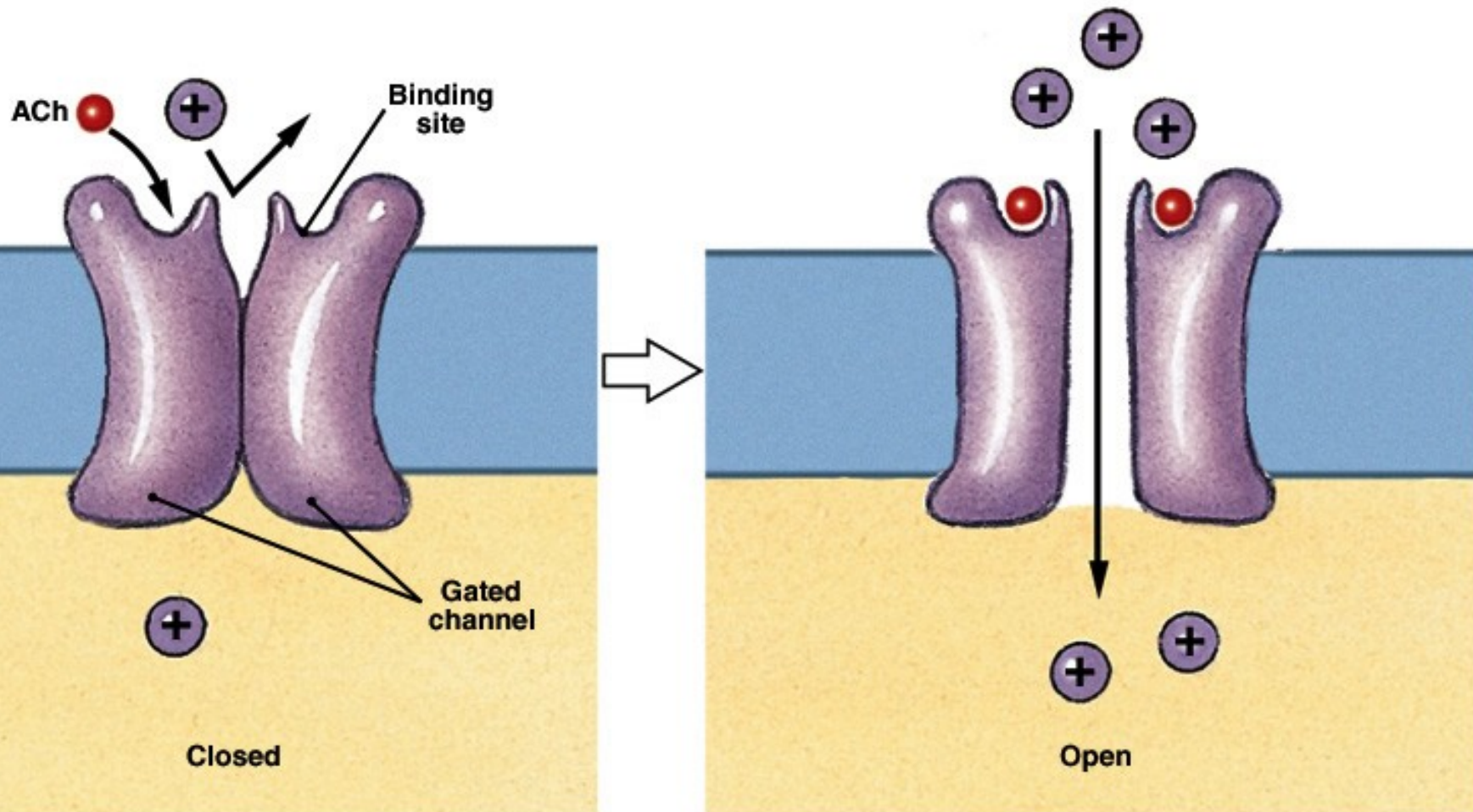
# Ion Channels

- ***Gated channels*** open and close in response to some sort of stimulus.
- ***Gated ion channels*** respond to:
  - **voltage** changes,
  - **ligands** (chemicals), and
  - **mechanical pressure**.

# Ion Channels

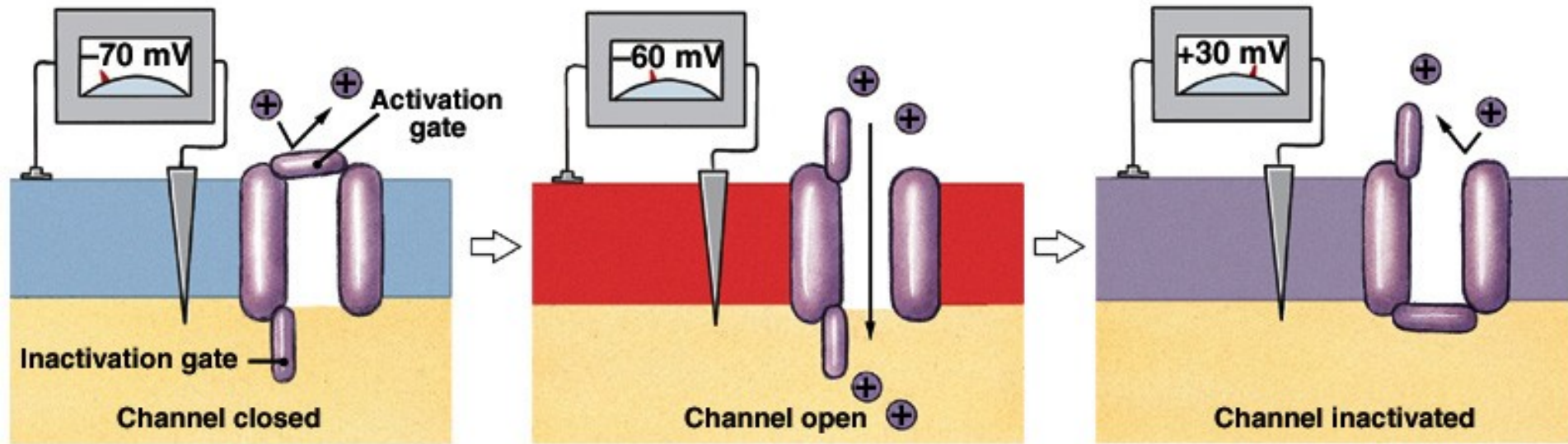
- *Voltage-gated channels* respond to a direct change in the **membrane potential**.
- *Ligand-gated channels* respond to a specific **chemical stimulus**.
- ***Mechanically gated ion channels*** respond to mechanical vibration or pressure.

# ***Ligand-gated ion channels***



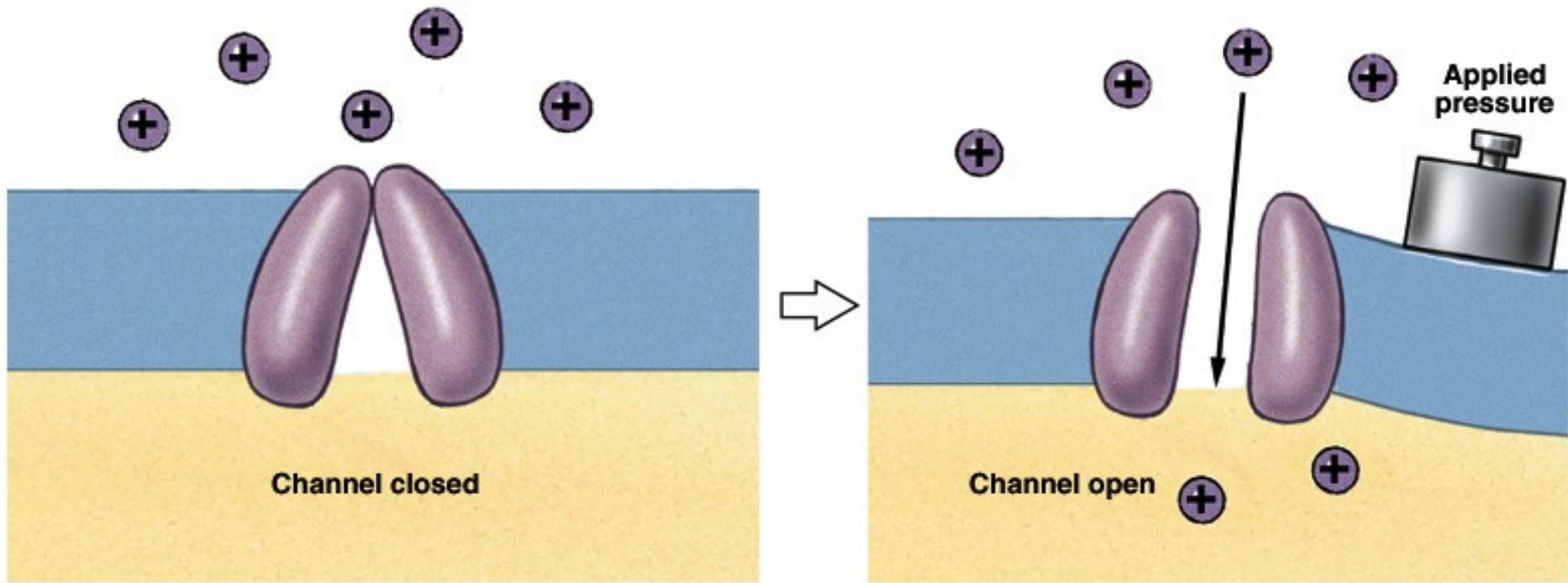
(a) Chemically regulated channel

# ***Voltage-gated ion channels***



**(b) Voltage-regulated channel**

# ***Mechanically gated ion channels***



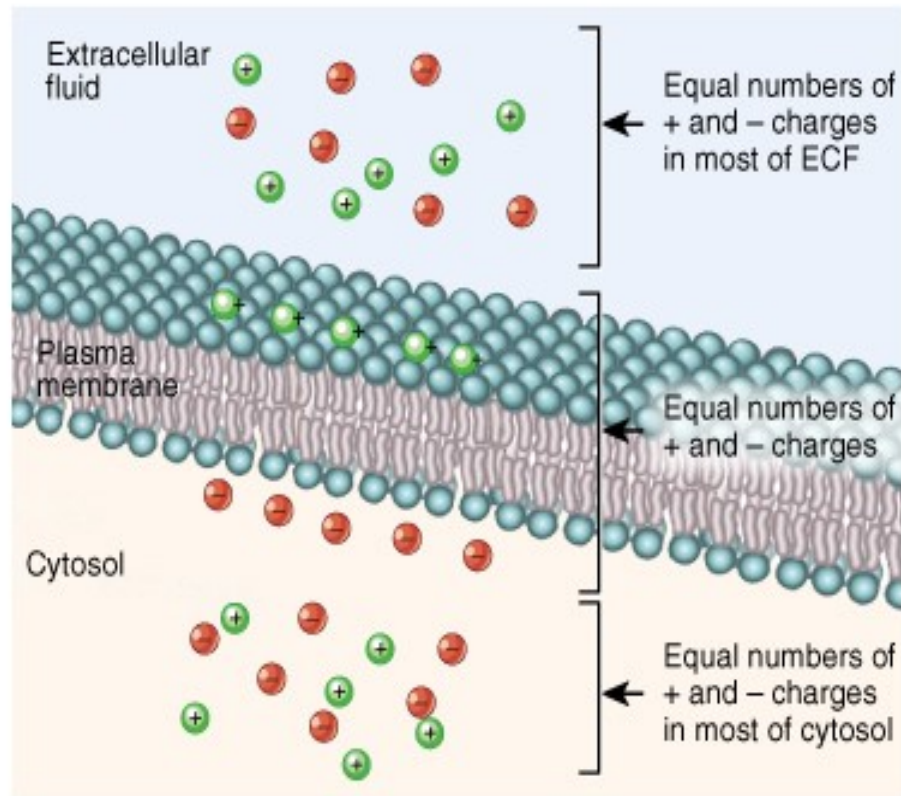
**(c) Mechanically regulated channel**

# Resting Membrane Potential

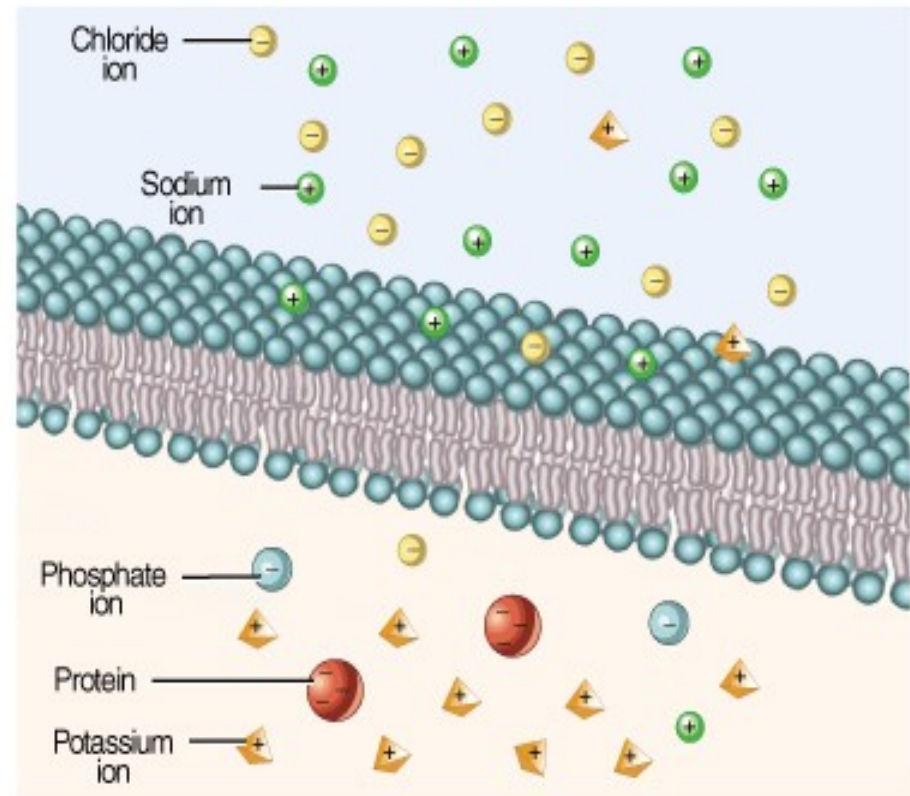
- The **membrane** of a nonconducting neuron is **positive outside** and **negative inside** owing to the distribution of different ions across the membrane and the relative permeability of the membrane toward  $\text{Na}^+$  and  $\text{K}^+$ .
- A typical value for the resting membrane potential is  $-70\text{mV}$ , and the membrane is said to be **polarized**.

# Resting Membrane Potential

- The *resting membrane potential* is determined by the unequal distribution of ions across the plasma membrane and the selective permeability of the membrane to  $\text{Na}^+$  and  $\text{K}^+$ .
- The **sodium-potassium pumps** compensate for slow leakage of  $\text{Na}^+$  into the cell by pumping it back out.



(a) Distribution of charges



(b) Distribution of ions

# Graded Potentials

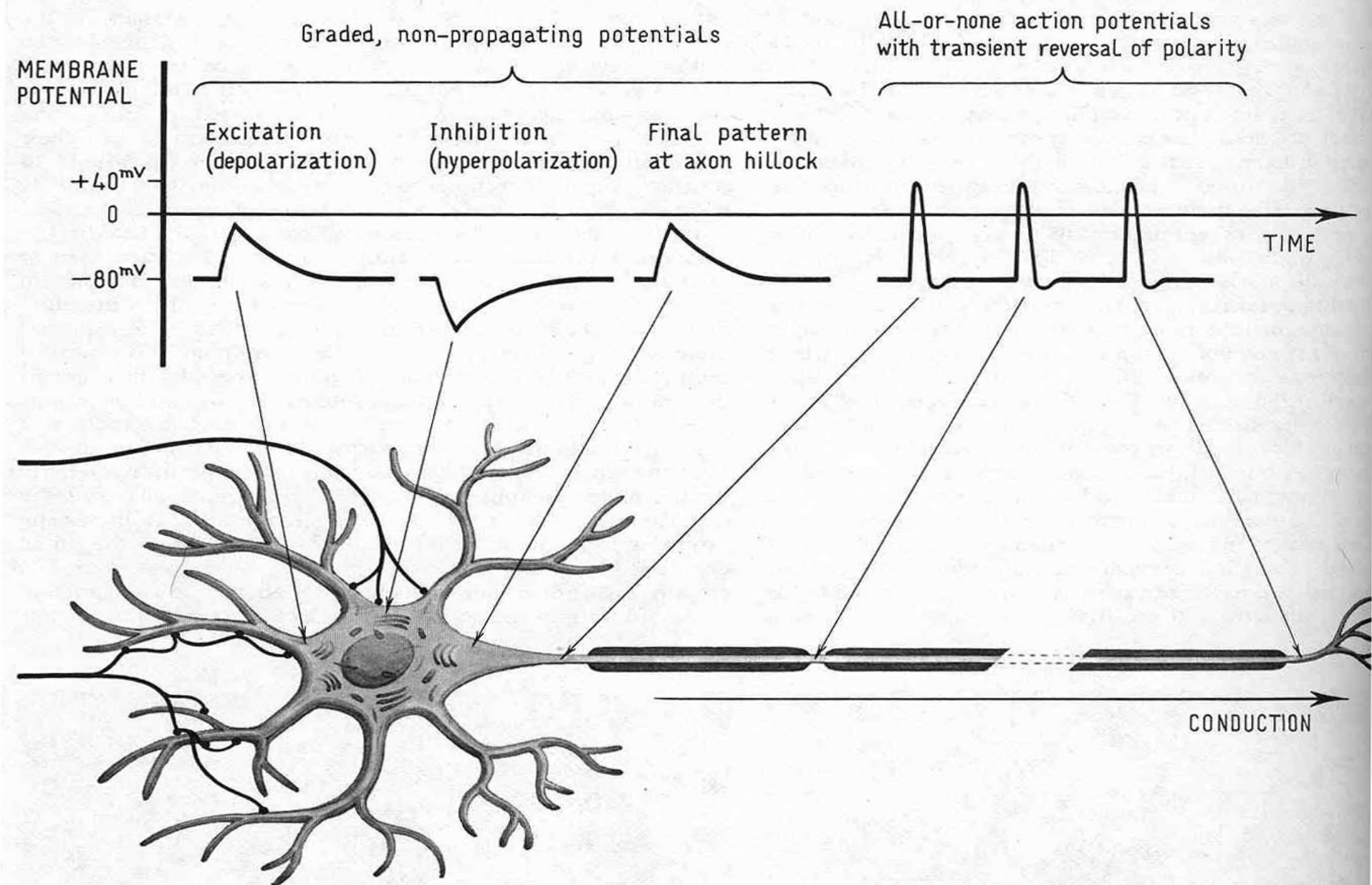
- A **graded potential** is a small deviation from the resting membrane potential that makes the membrane either more polarized (**hyperpolarization**) or less polarized (**depolarization**).
- Graded potentials occur most often in the **dendrites** and **cell body** of a neuron.
- The signals are *graded*, meaning they vary in amplitude (size), depending on the strength of the stimulus and localization.

# Graded Potentials

- When a stimulus causes mechanically gated or ligand-gated channels to open or close in the cell's plasma membrane, a **graded potential** arises.
- A **graded potential** is a small deviation from the resting membrane potential that makes the membrane either more polarized (**hyperpolarization**, inside more negative) or less polarized (**depolarization**, inside less negative ).

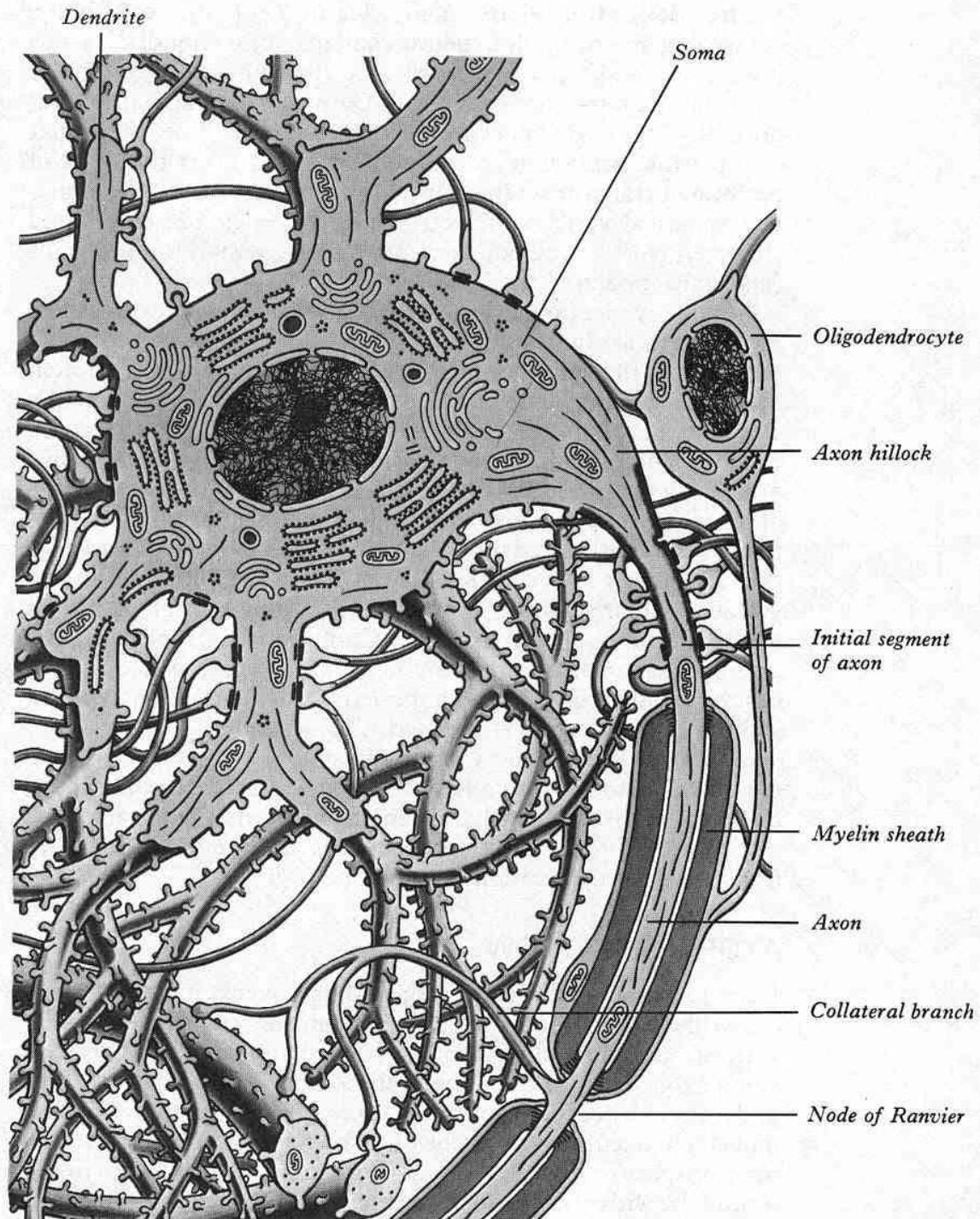
# Graded Potentials

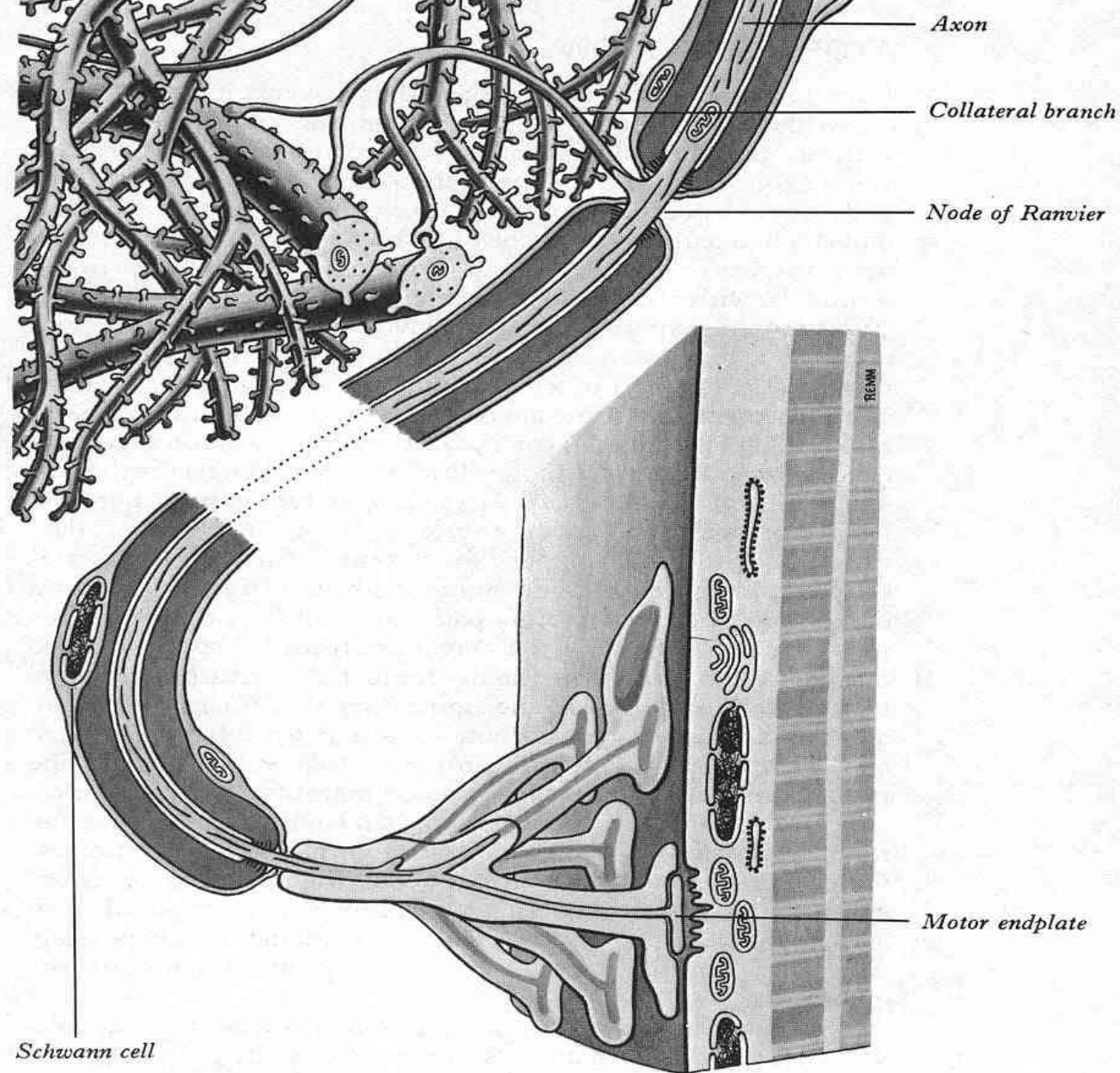
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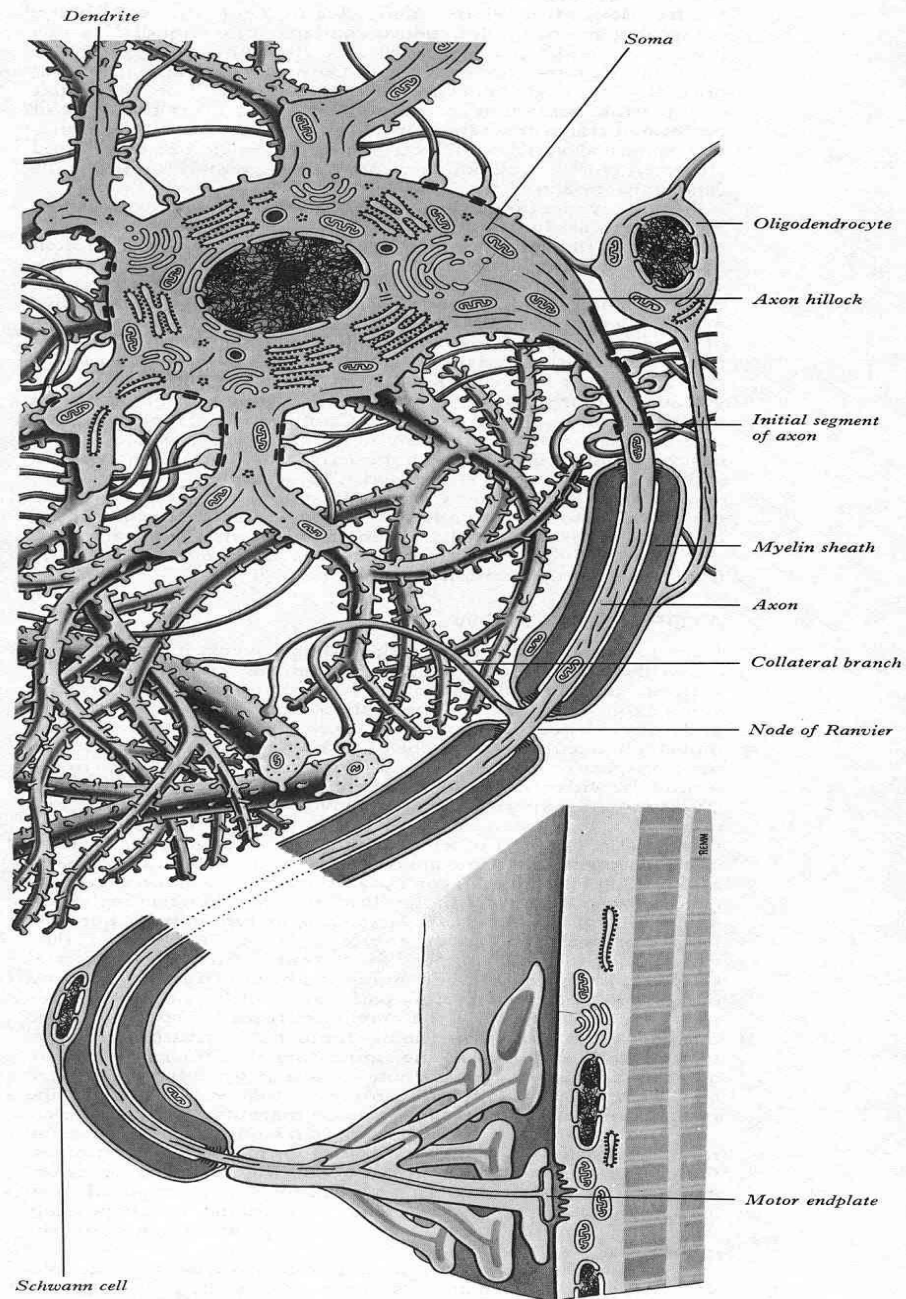
7.16 A diagram showing the types of change in electrical potential which can be recorded across the cell membrane of a motor neuron at the points indicated by the arrows. Excitatory and inhibitory synapses on the surfaces of the dendrites and soma cause local graded changes of potential

which summate at the axon hillock, and may initiate a series of all-action potentials, which in their turn are conducted along the axon to the effector terminals.





7.17 A schematic drawing of the ultrastructure of a motor neuron, showing part of its dendritic field (above left); the dendrites are studded with spines which are contacted by different types of synaptic terminal. The cytoplasm of the neuronal soma contains stacks of rough endoplasmic reticulum, and other organelles. See text for a detailed description.



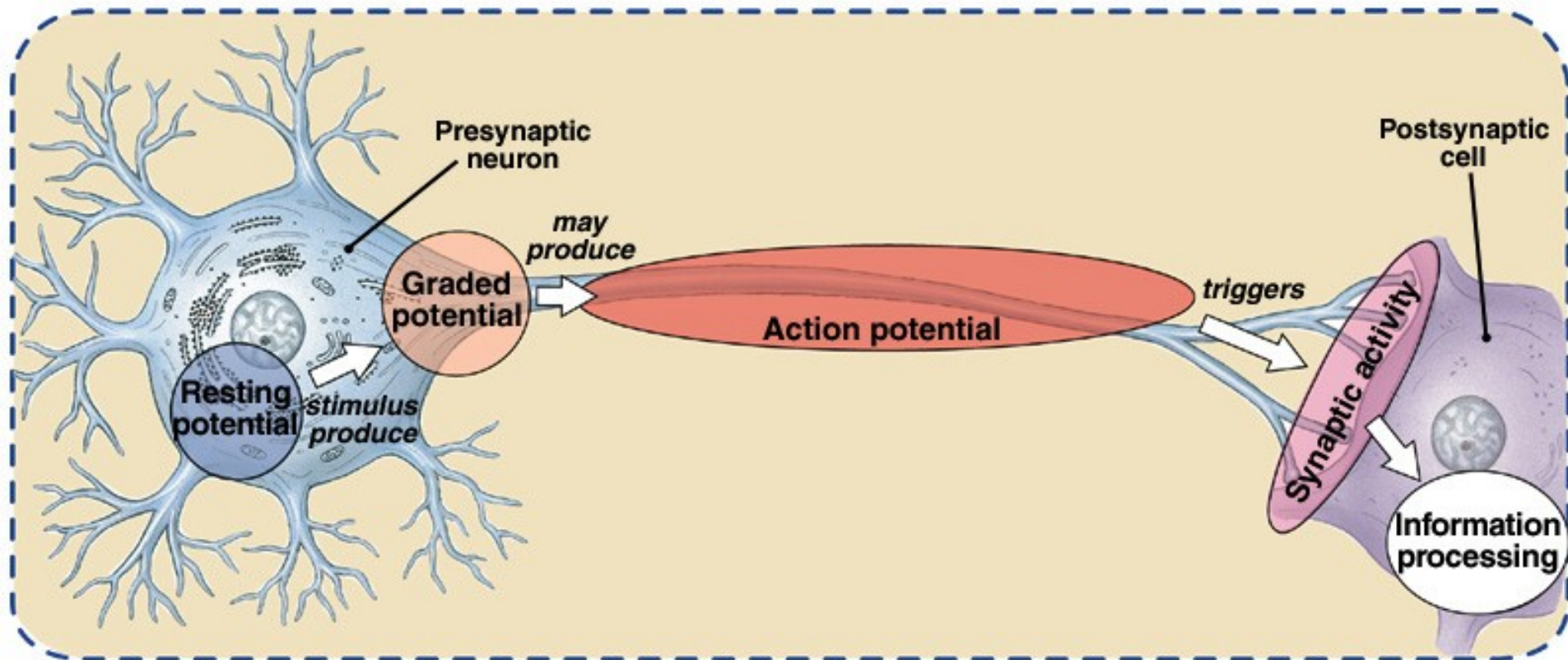
7.17 A schematic drawing of the ultrastructure of a motor neuron, showing part of its dendritic field (above left); the dendrites are studded with spines which are contacted by different types of synaptic terminal. The cytoplasm of the neuronal soma contains stacks of rough endoplasmic reticulum, and other organelles. See text for a detailed description.

# Action Potential

- An **action potential** (AP) or *impulse* is a sequence of rapidly occurring events that decrease and eventually reverse the membrane potential (**depolarization**) and then restore it to the resting state (**repolarization**).

# Action Potential

- During an action potential, voltage-gated  $\text{Na}^+$  and  $\text{K}^+$  channels open in sequence.
- The **propagation** speed of a nerve impulse is not related to stimulus strength.
- **Larger-diameter fibers** conduct impulses faster than those with smaller diameters.



# Action Potential

- **Myelinated** fibers conduct impulses faster than **unmyelinated** fibers.
- Nerve fibers conduct impulses faster when warmed and slower when cooled.

# Action Potential

- During the ***refractory period*** , another impulse cannot be generated at all (*absolute refractory period*) or can be triggered only by a suprathreshold stimulus (*relative refractory period*).

# Action Potential

- An action potential *conducts* or **propagates** (travels) from point to point along the membrane;
- The traveling action potential is a **nerve impulse**.
- Local anesthetics prevent opening of voltage-gated  $\text{Na}^+$  channels so nerve impulses cannot pass the obstructed region.

# Action Potential

- According to the ***all-or-none principle***, if a stimulus is strong enough to generate an action potential, the impulse travels at a constant and maximum strength for the existing conditions;
- A stronger stimulus will not cause a large impulse.

# Action Potential

- The step-by-step depolarization of each adjacent area of the plasma membrane is called *continuous conduction*.
- Nerve impulse conduction in which the **impulse jumps** from neurofibral node to node is called *saltatory conduction*.

# Action Potential

- The intensity of a stimulus is coded in the rate of impulse production, i.e., the frequency of action potentials.
- The chemical and physical environment of a neuron influences generation and propagation of action potentials.

# Action Potential

- Nerve and muscle action potentials differ in size of the resting membrane potential, duration of the impulses, and velocity of conduction of the impulse.

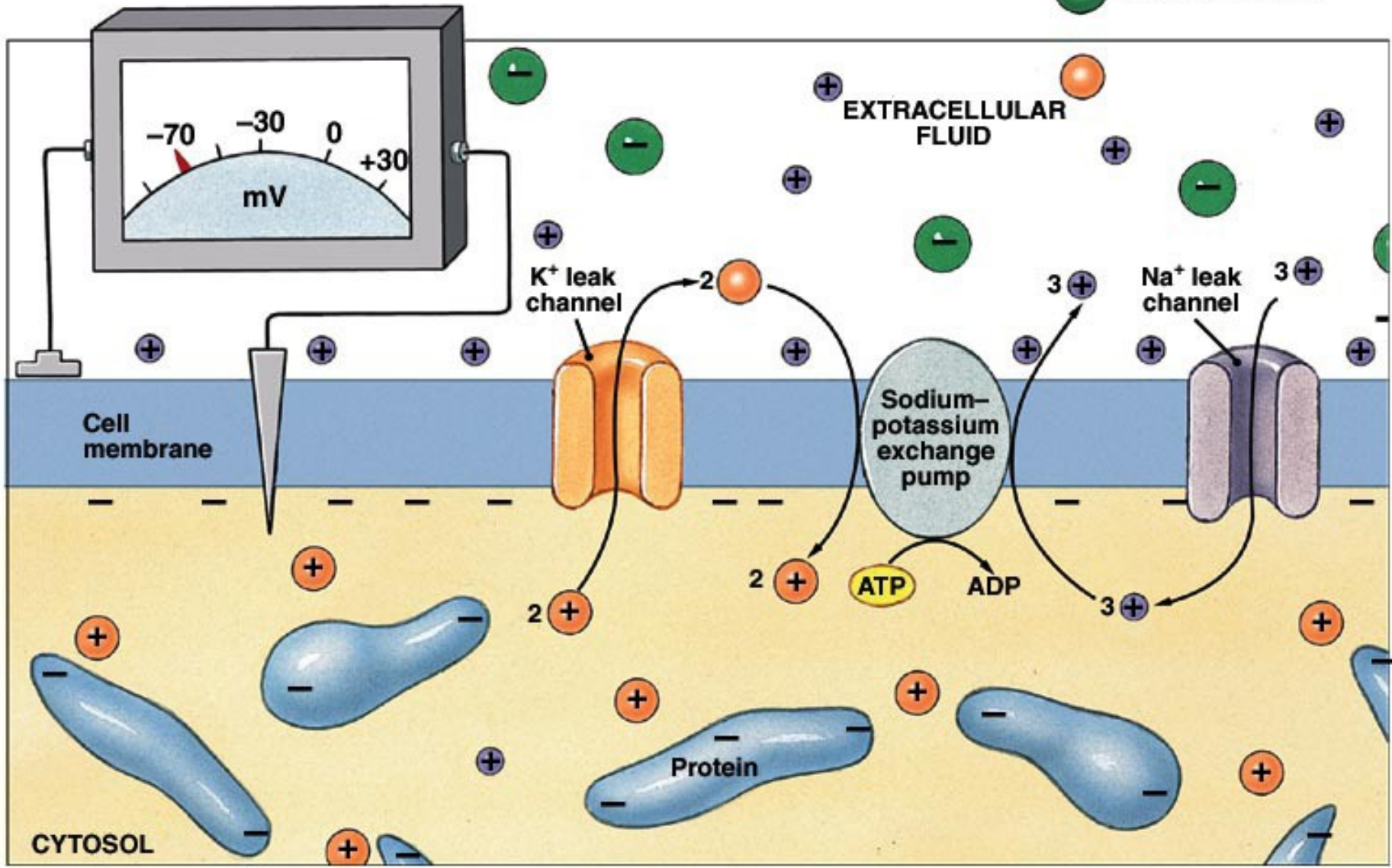
# Action Potential

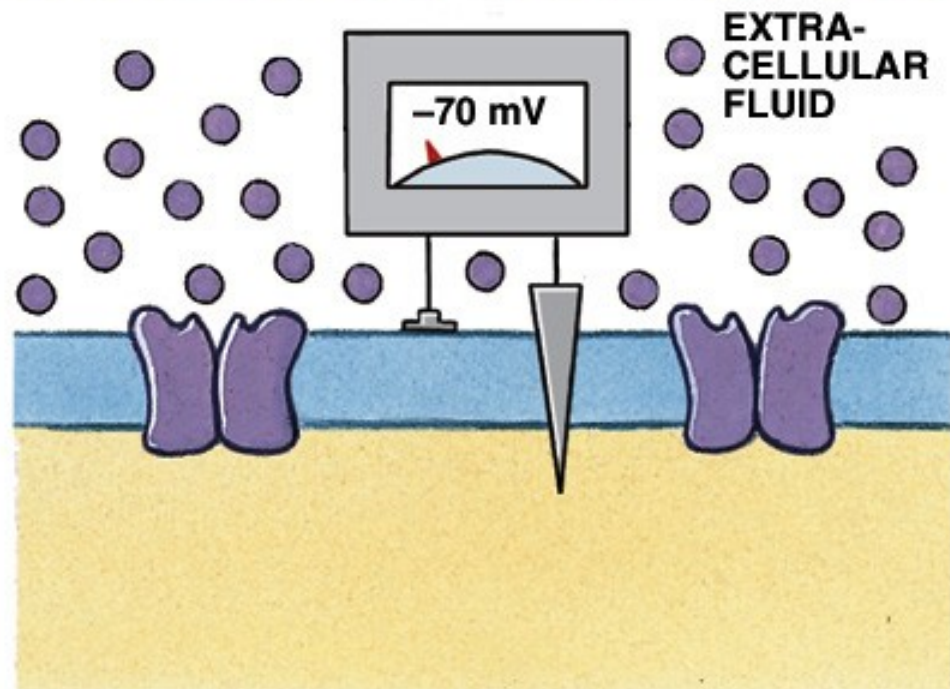
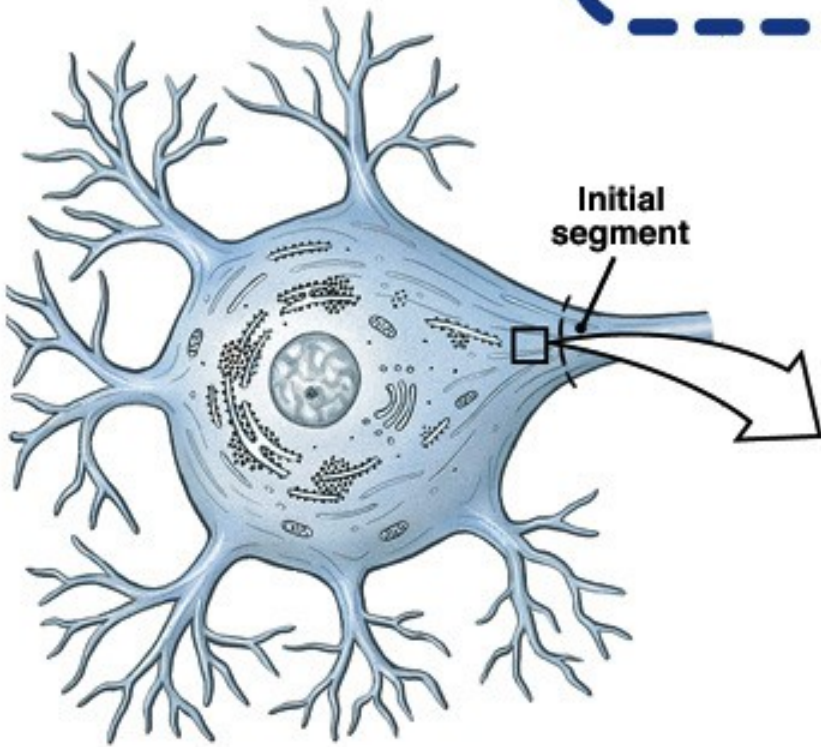
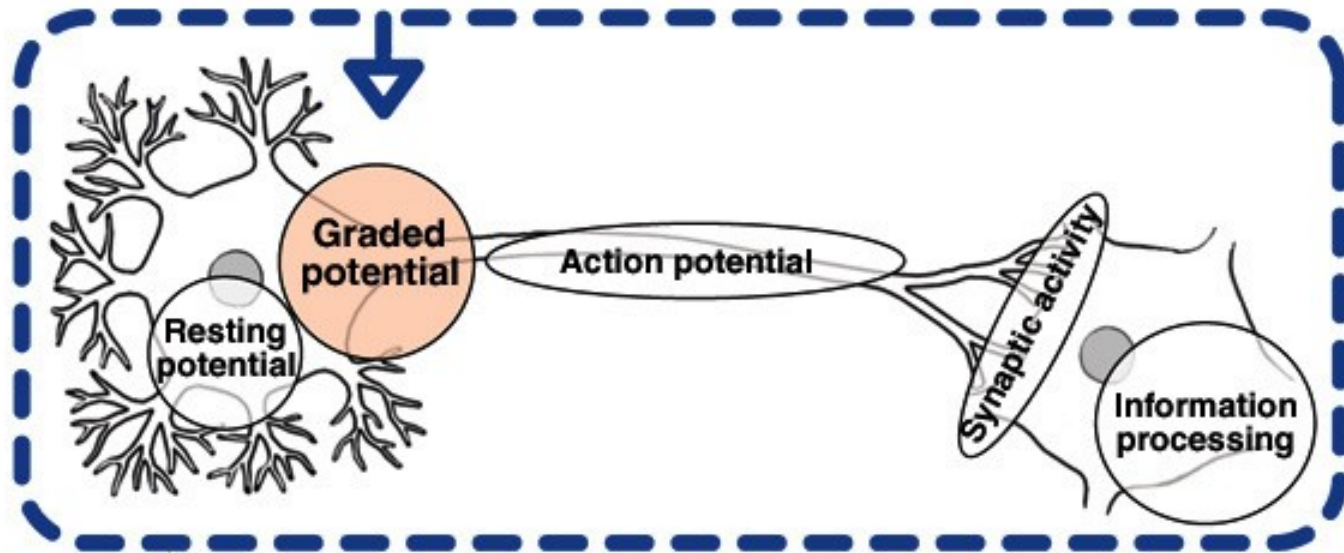
- **Graded** and **action** potentials differ in amplitude, duration, types of channels used, location, polarity, propagation, and refractory period.
- The various differences between graded potentials and action potentials are summarized in Table 12.2.

# Action Potential

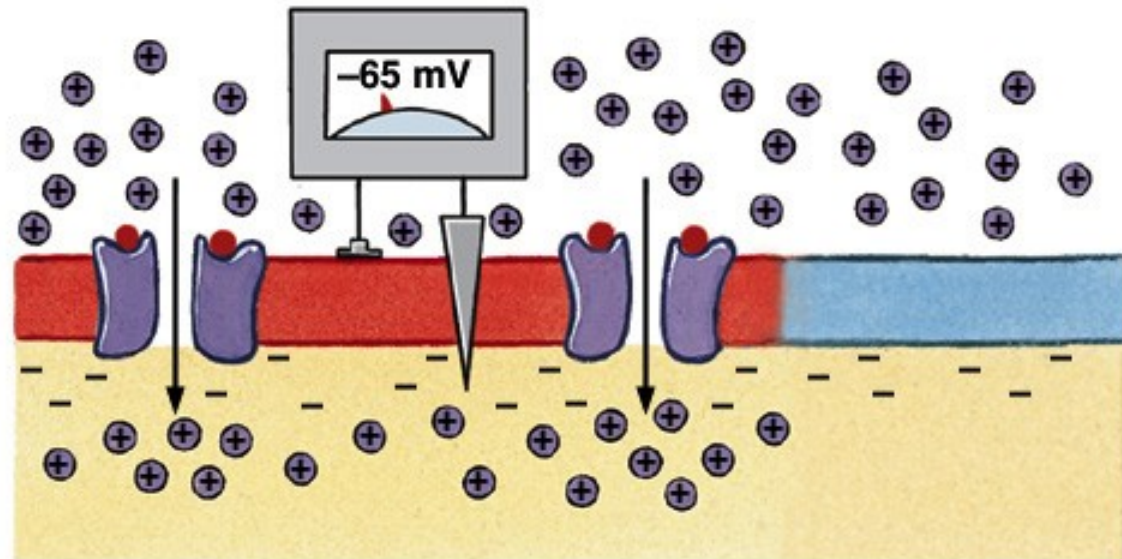
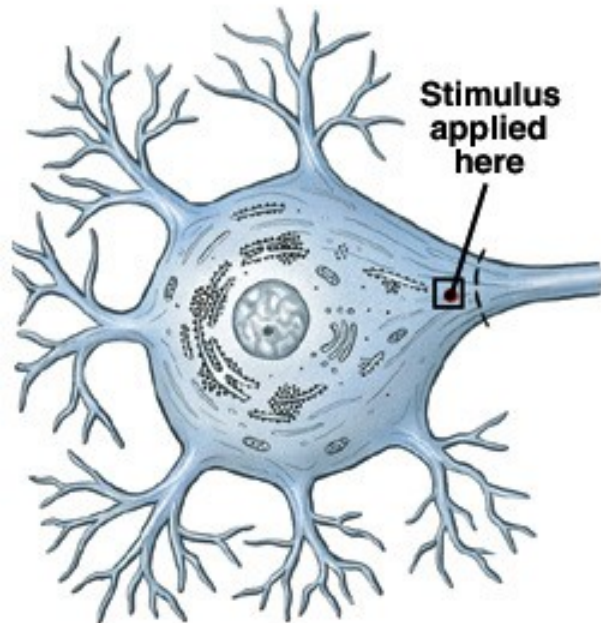
- The **propagation speed** of a nerve impulse is not related to stimulus strength.
- **Larger-diameter** fibers conduct impulses faster than those with smaller diameters.
- **Myelinated** fibers conduct impulses faster than unmyelinated fibers.
- Nerve fibers conduct impulses faster when **warmed** and slower when cooled.

- $\oplus$  Sodium ion ( $\text{Na}^+$ )
- $\oplus$  Potassium ion ( $\text{K}^+$ )
- $\ominus$  Chloride ion ( $\text{Cl}^-$ )

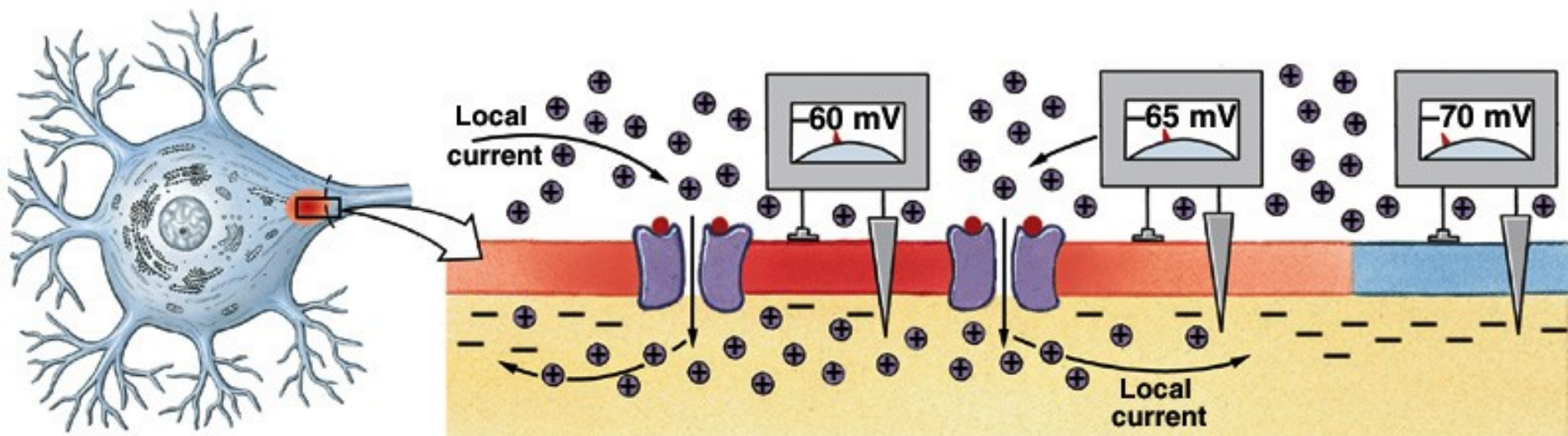




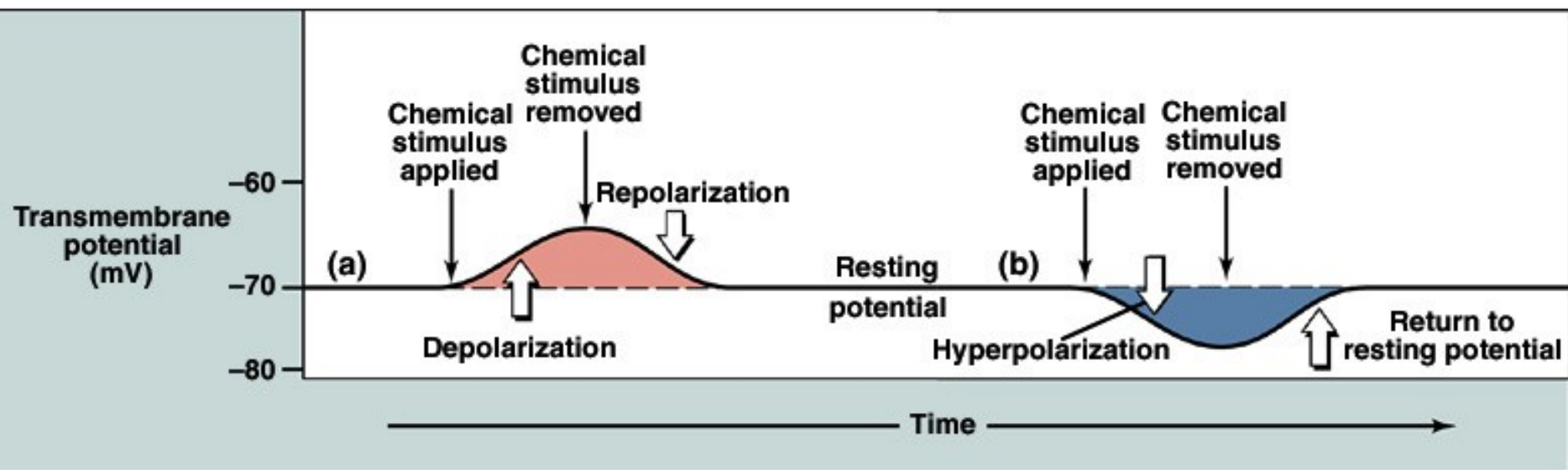
(a) Resting membrane with closed chemically regulated sodium ion channels

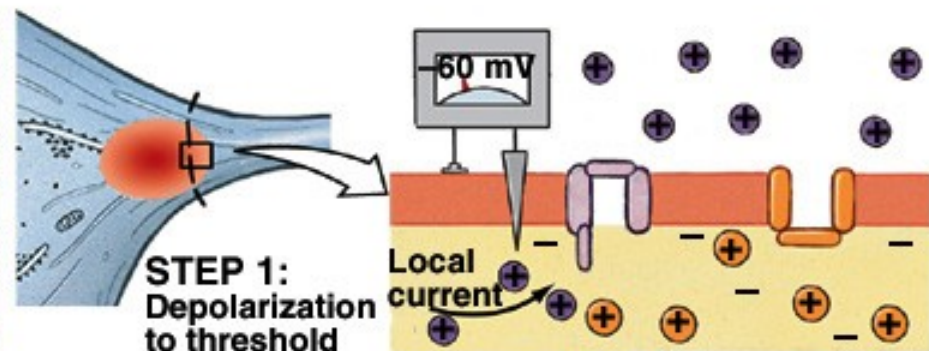
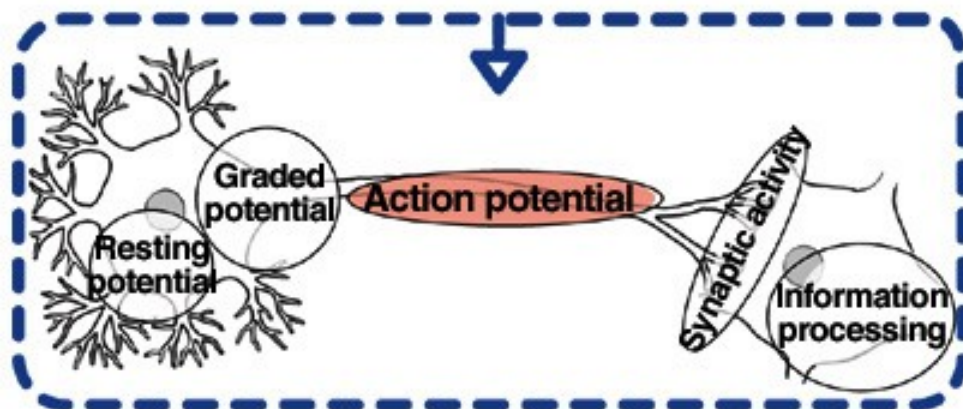


**(b)** Membrane exposed to chemical that opens these sodium ion channels

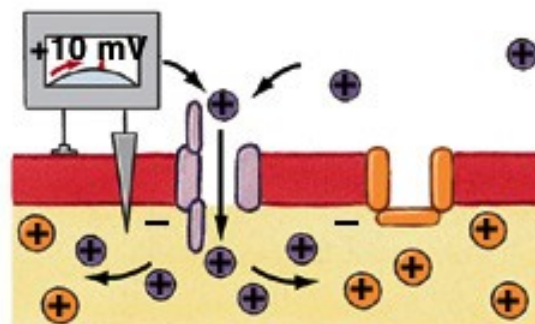


**(c) Spread of sodium ions inside cell membrane produces a local current that depolarizes adjacent portions of the cell membrane**

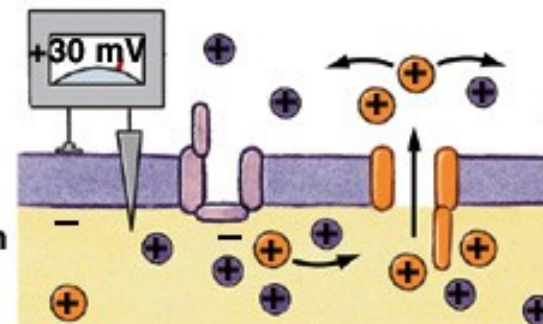




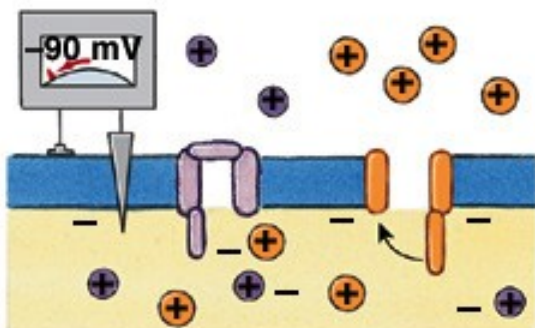
**STEP 2:**  
Activation of sodium  
channels and rapid  
depolarization



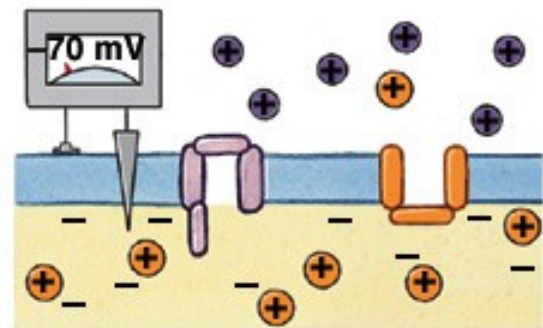
**STEP 3:**  
Inactivation of sodium  
channels and activation  
of potassium channels

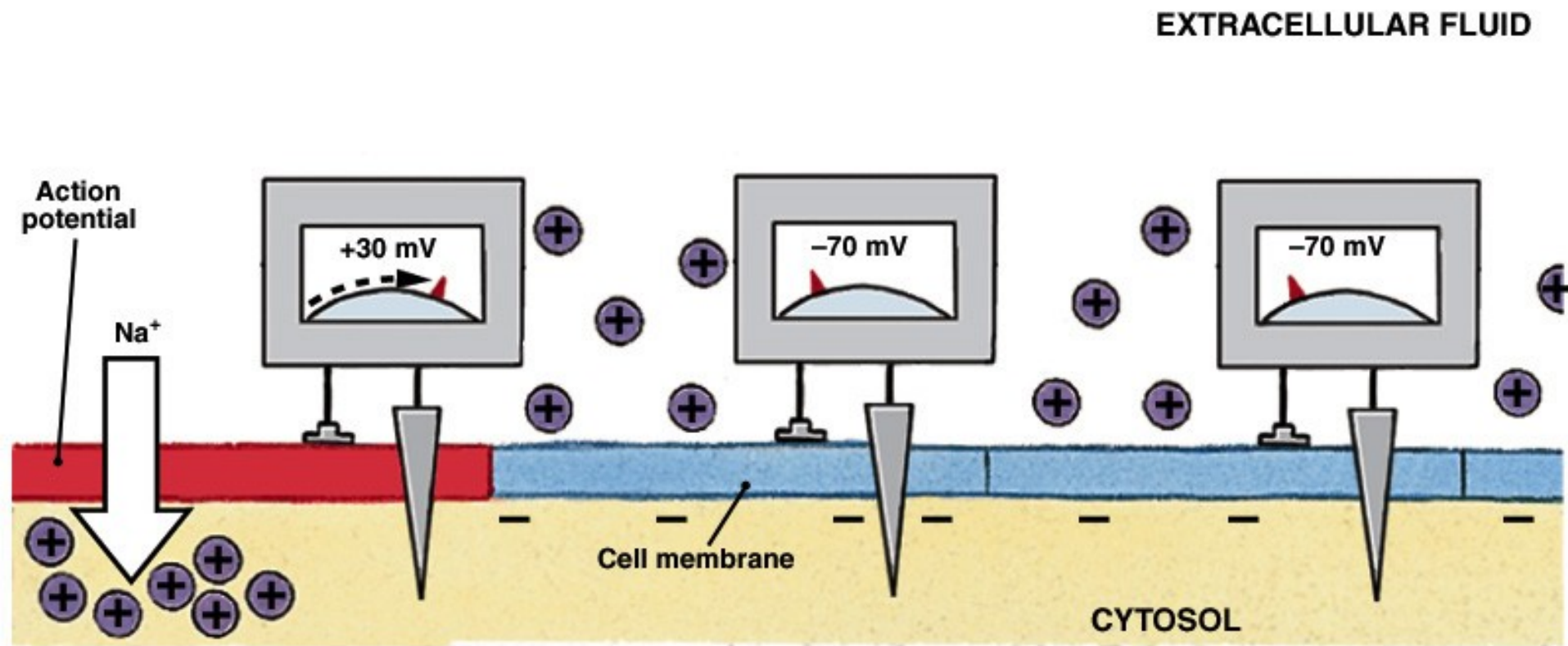


**STEP 4:**  
The return to  
normal permeability

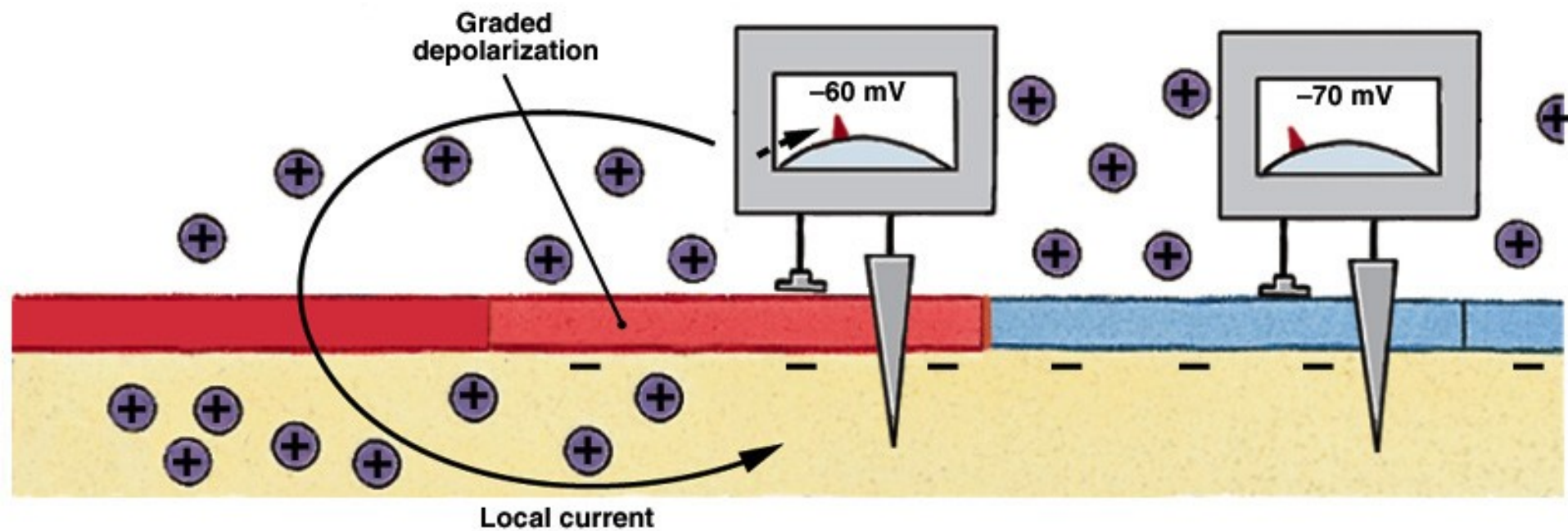


**STEP 5:**  
Resting state

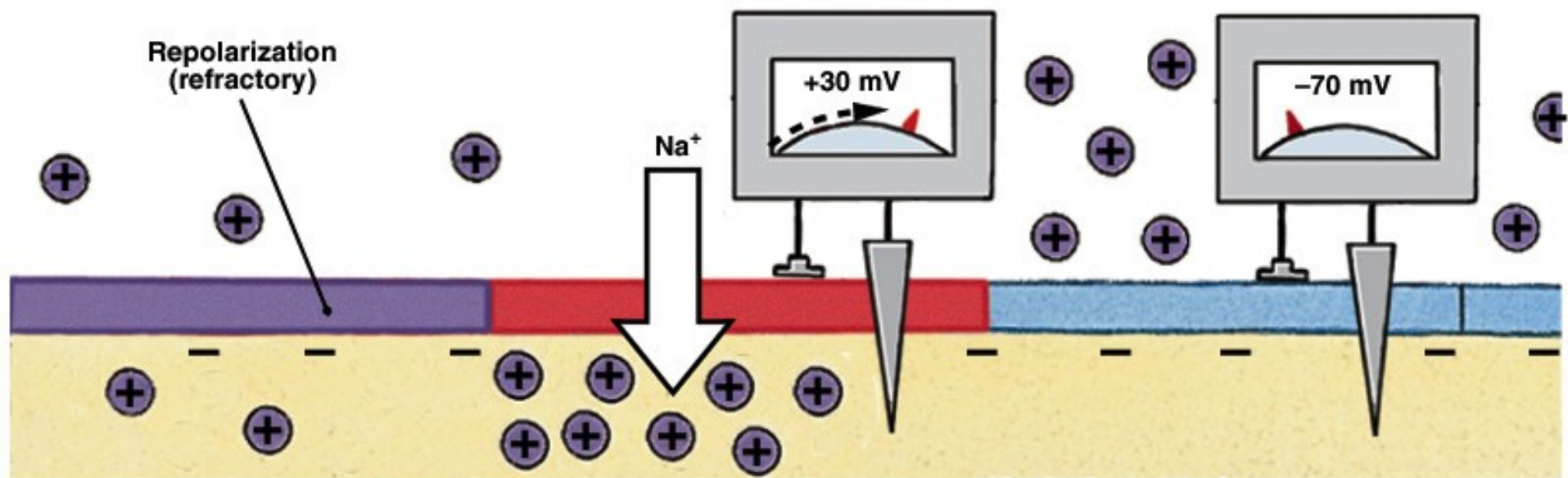




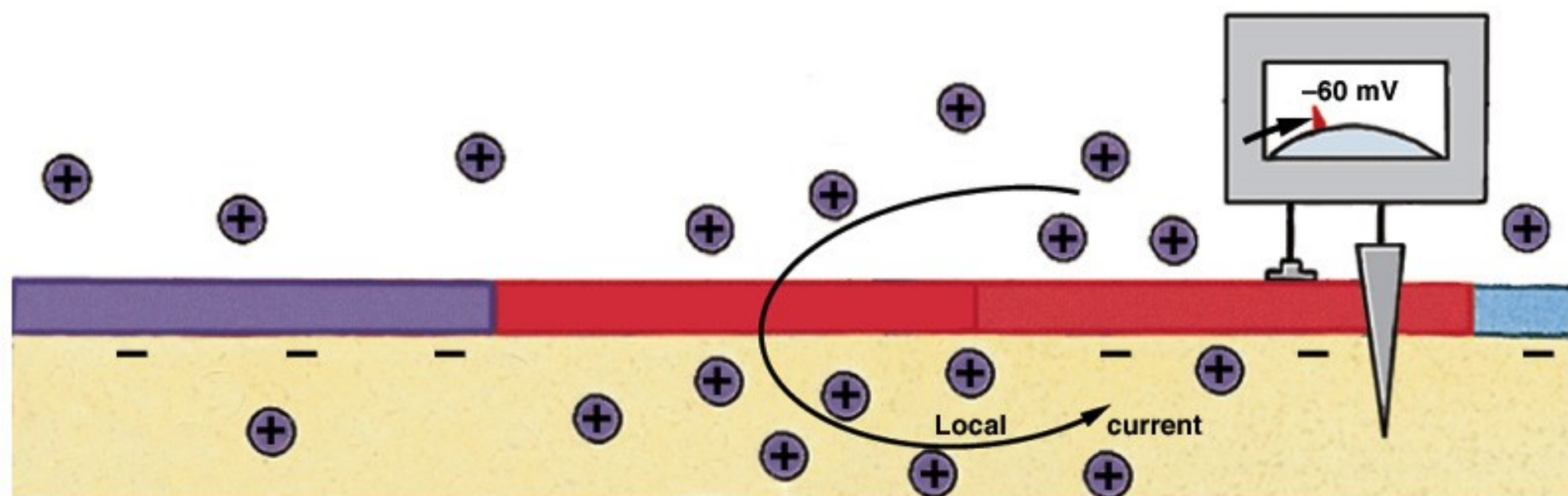
a) As an action potential develops in the initial segment, the transmembrane potential depolarizes to +30



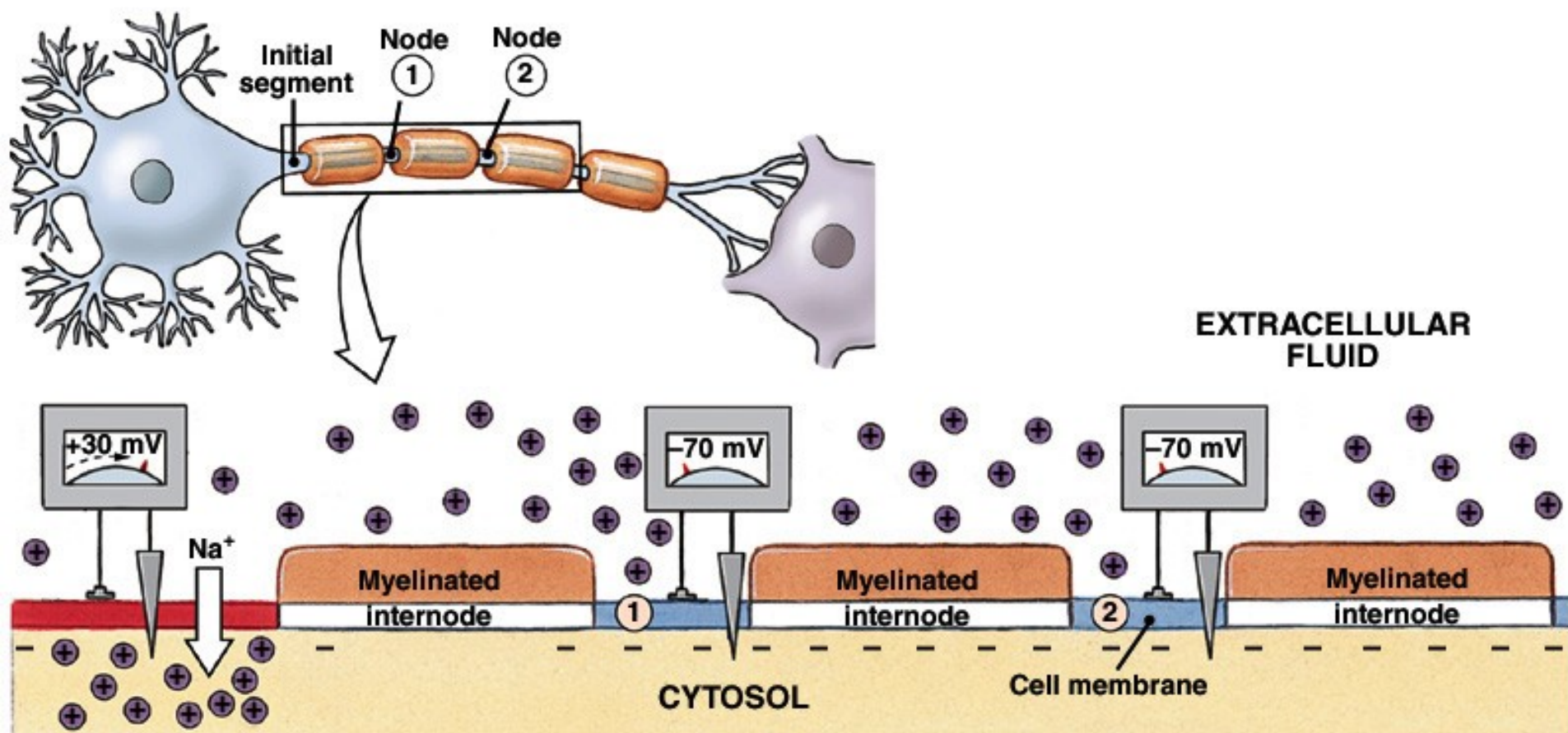
**(b) A local current depolarizes the adjacent portion of the membrane to threshold.**



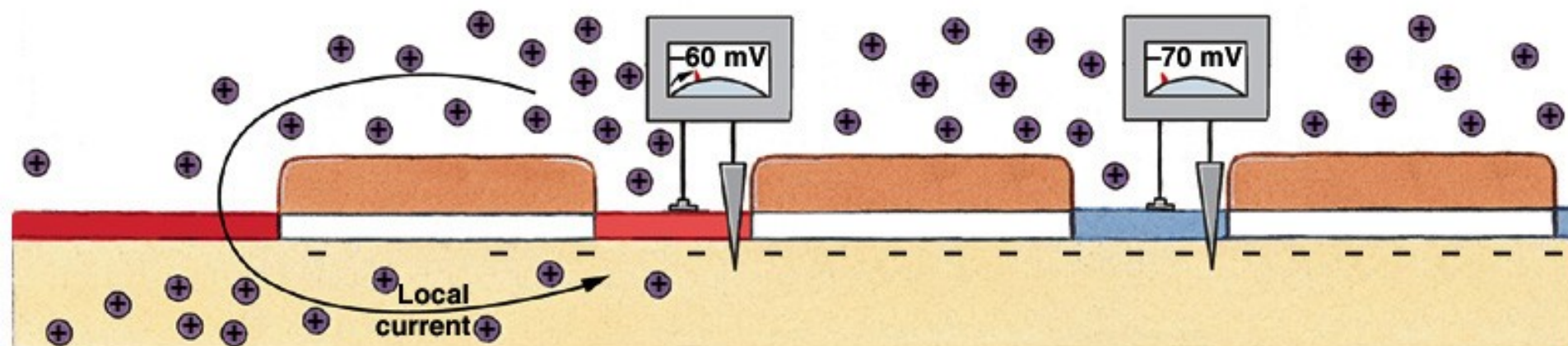
(c) An action potential develops at this location, and the initial segment enters the refractory period.



(d) A local current depolarizes the adjacent portion of the membrane to threshold, and the cycle is repeated.

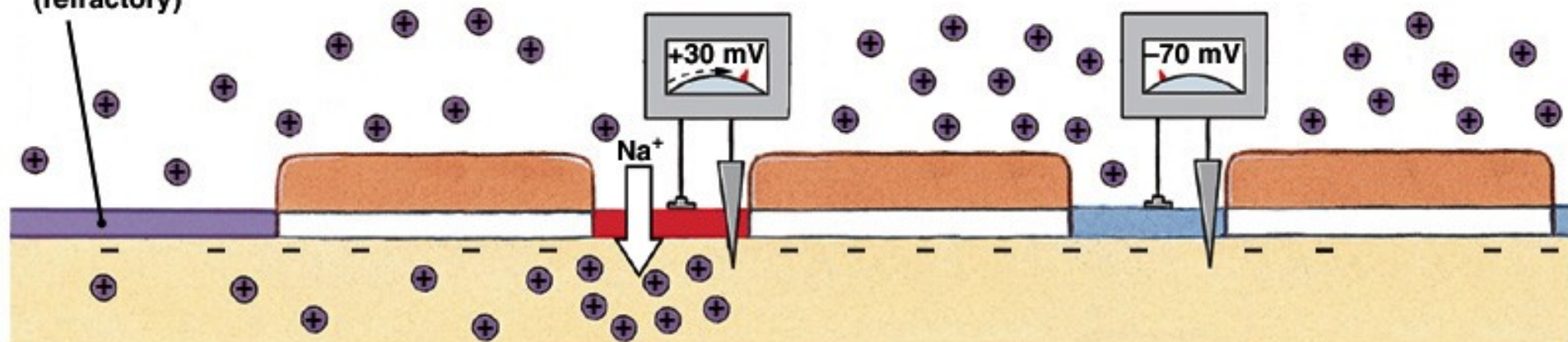


(a) Action potential at initial segment

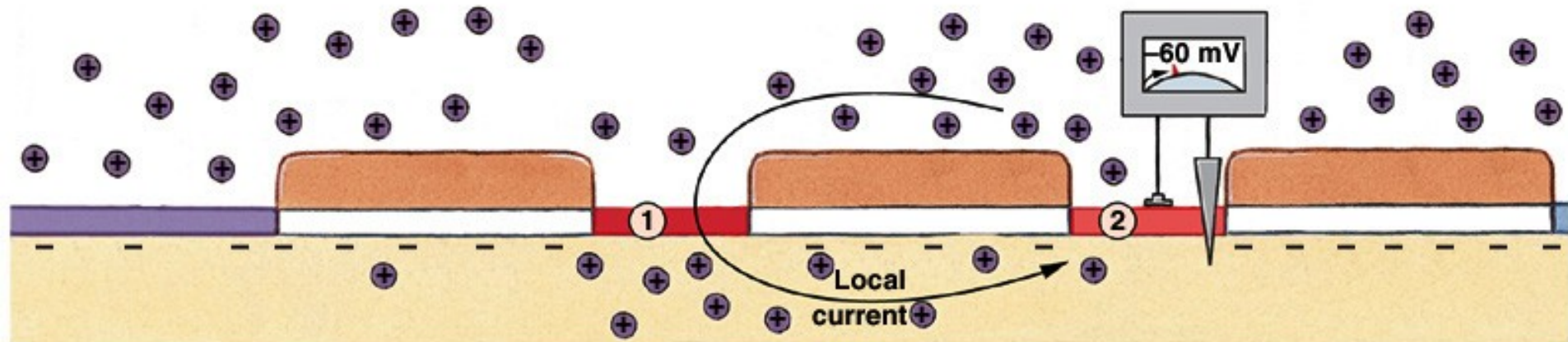


**(b)** Depolarization to threshold at node 1

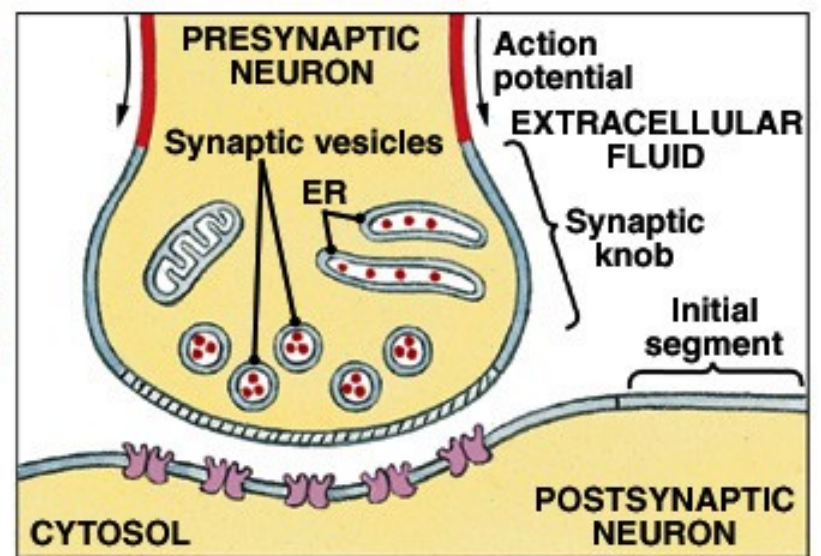
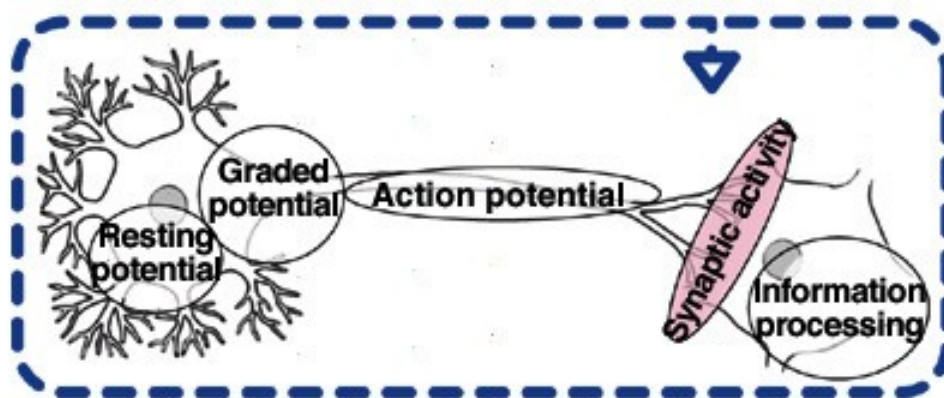
Repolarization  
(refractory)



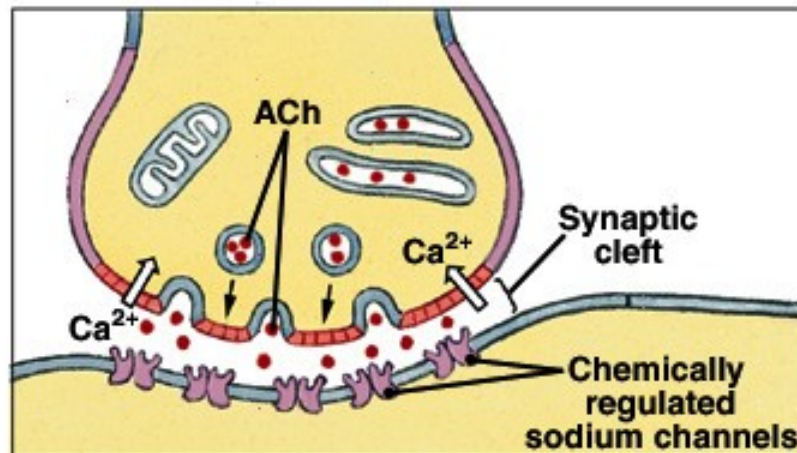
(c) Action potential at node 1



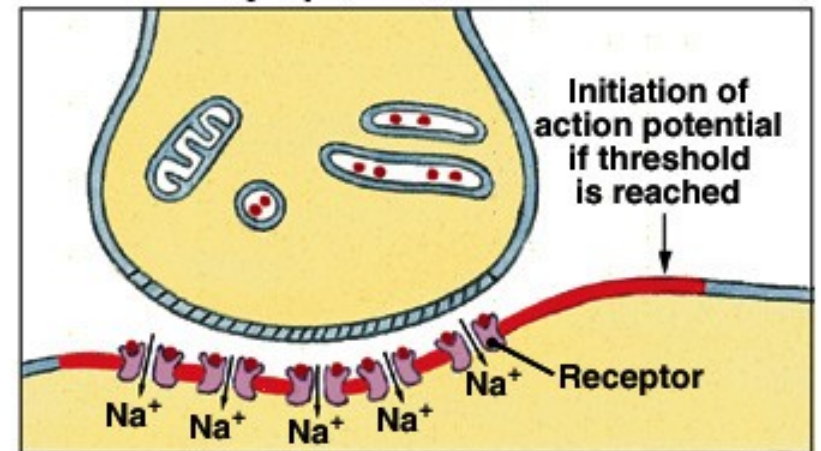
(d) Depolarization to threshold at node 2



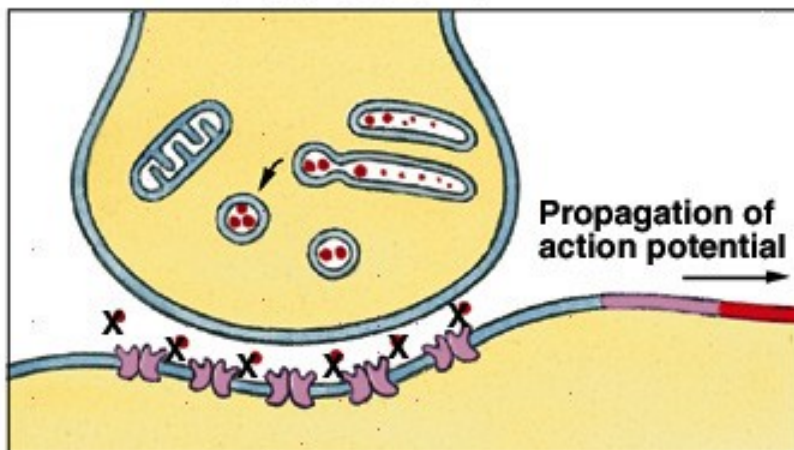
(a) STEP 1: Arrival of action potential at synaptic knob



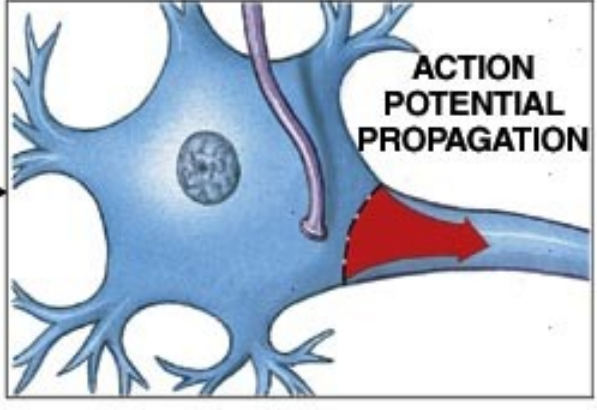
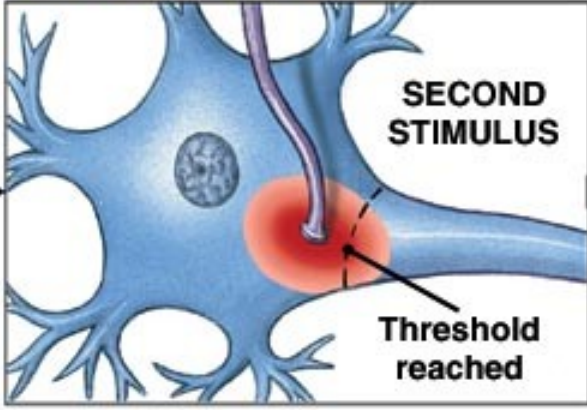
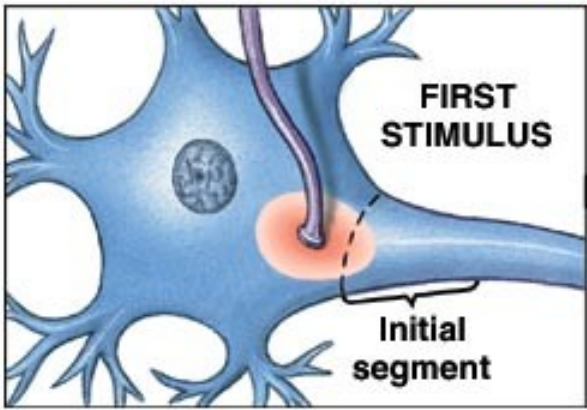
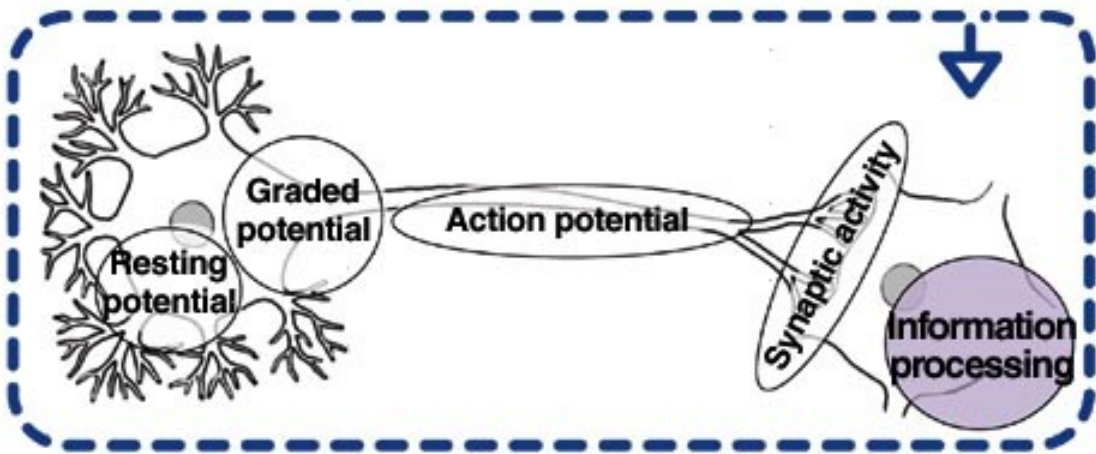
(b) STEP 2: Entry of extracellular  $\text{Ca}^{2+}$  and exocytosis of ACh



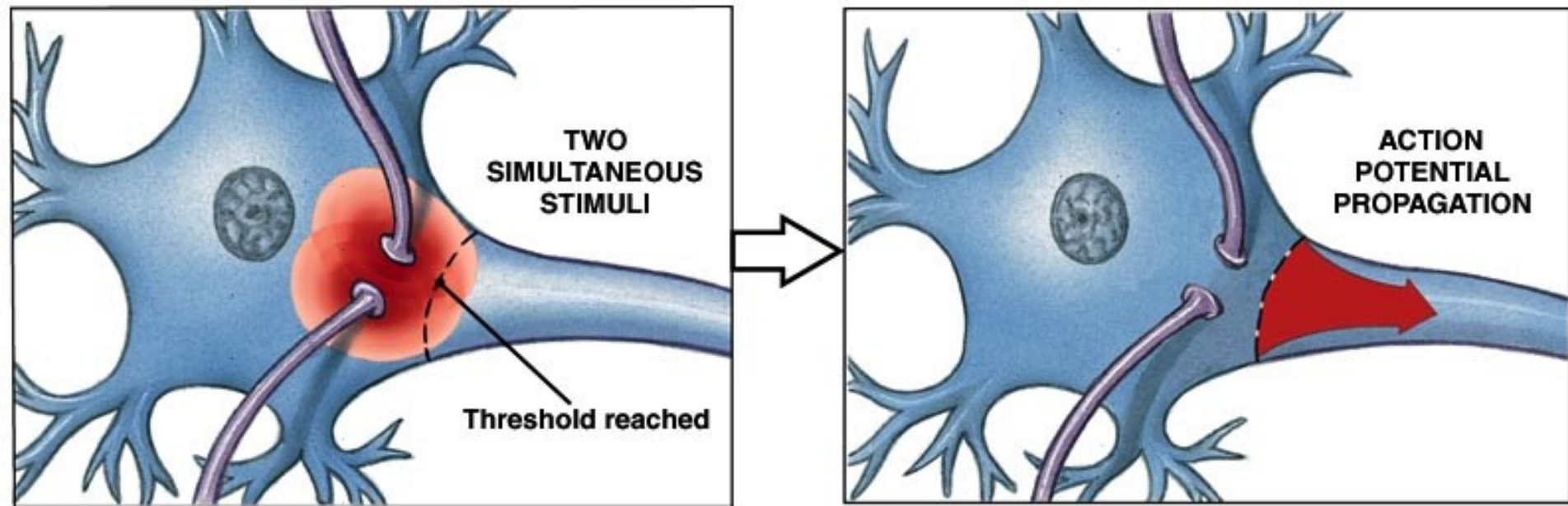
(c) STEP 3: Binding of ACh to receptors and depolarization of postsynaptic membrane may bring initial segment to threshold



(d) STEP 4: Removal of ACh by acetylcholinesterase (AChE)



(a) Temporal summation



**(b) Spatial summation**

# SIGNAL TRANSMISSION AT SYNAPSES

- A ***synapse*** is the functional junction between one neuron and another or between a neuron and an **effector** such as a muscle or gland.

# Electrical Synapses

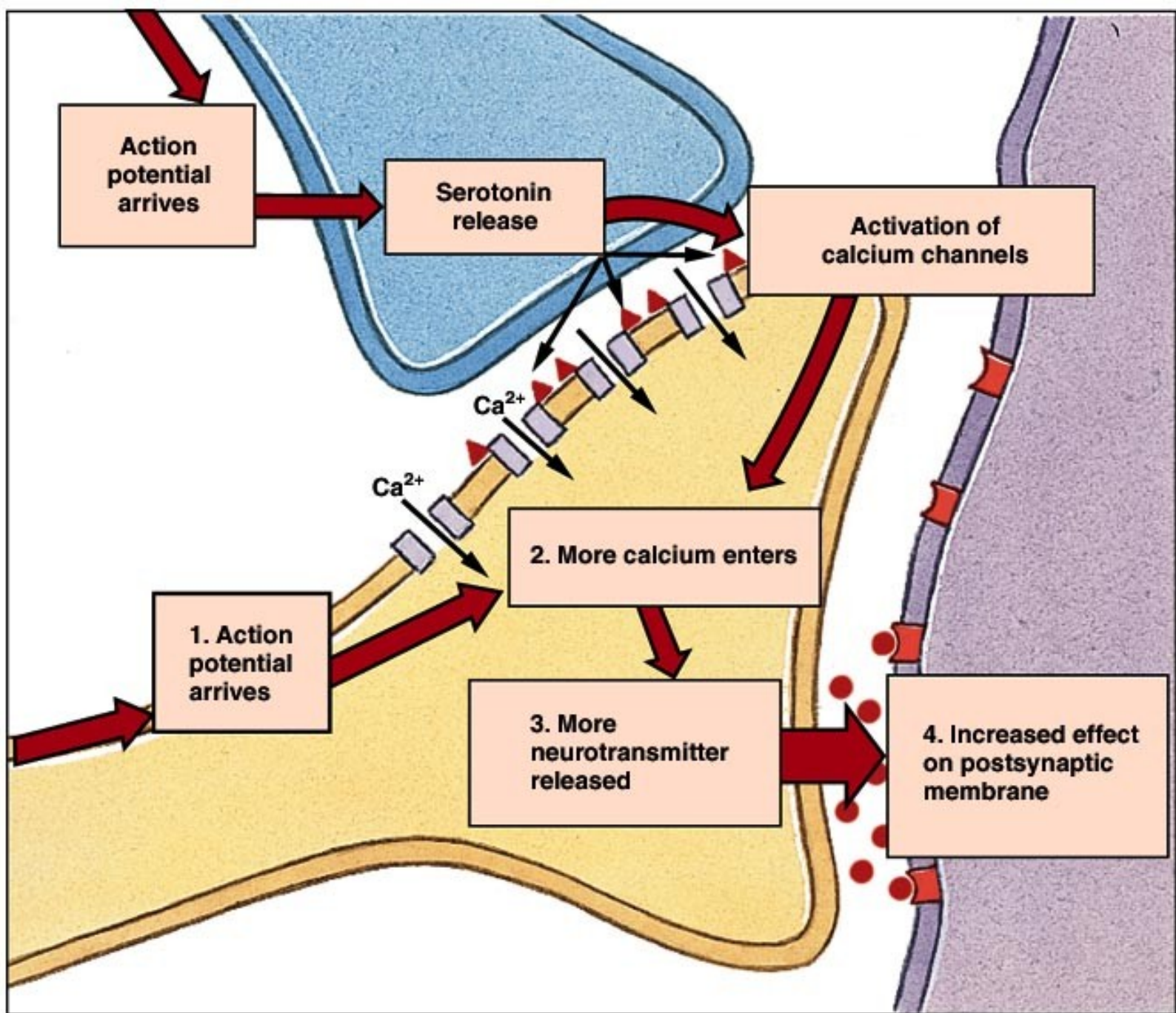
- At an *electrical synapse*, ionic current spreads directly from one cell to another through gap junctions.
- Electrical synapses allow faster communication, can synchronize the activity of a group of neurons or muscle fibers, and may set up two-way transmission of impulses.

# Chemical Synapses

- At a ***chemical synapse***, there is only one-way information transfer from a **presynaptic** neuron to a **postsynaptic neuron**.
- **Neurotransmitters** at chemical synapses cause either an excitatory or inhibitory graded potential.
- An ***excitatory neurotransmitter*** is one that can depolarize or make less negative the postsynaptic neuron's membrane, bringing the membrane potential closer to threshold.

# Excitatory Postsynaptic Potential (EPSP)

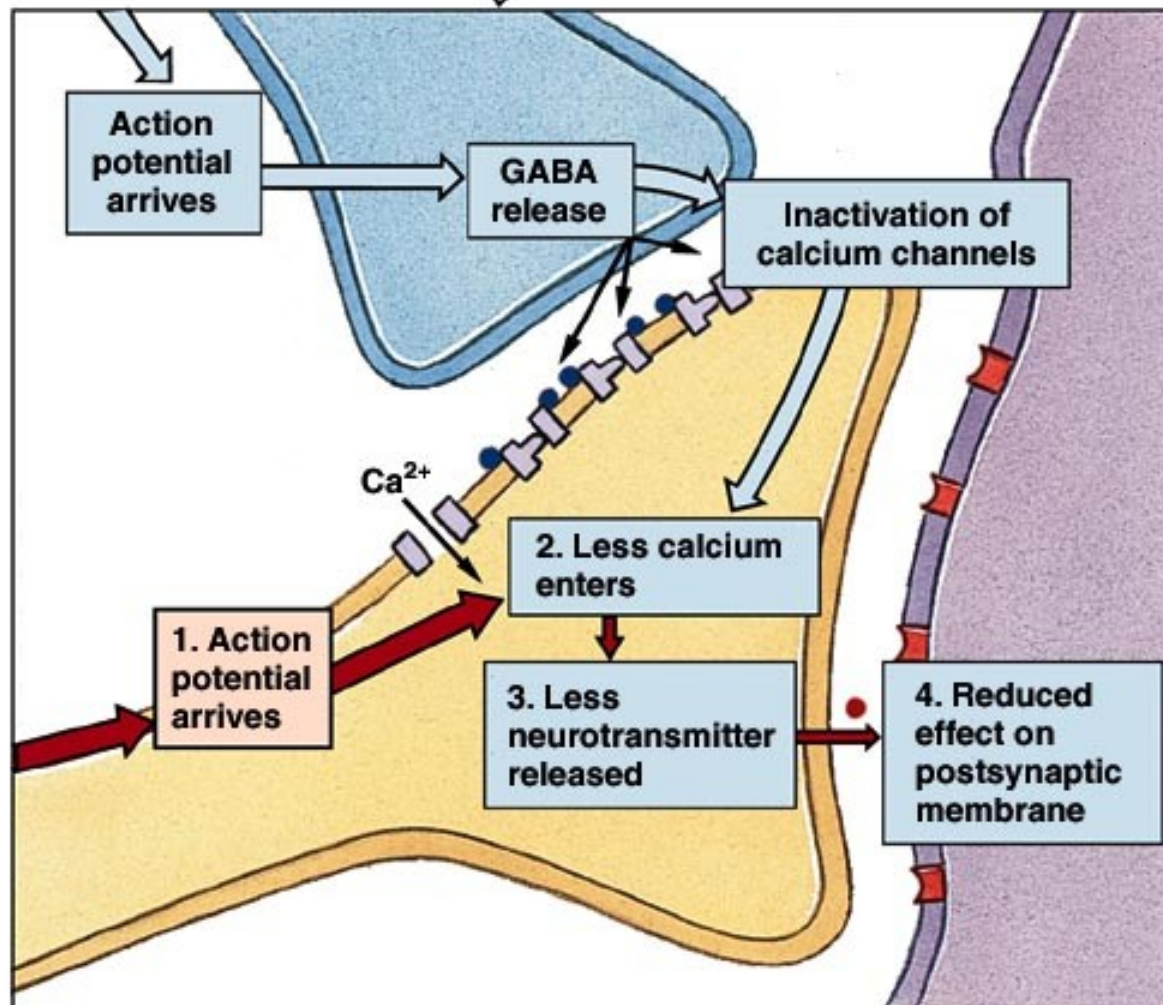
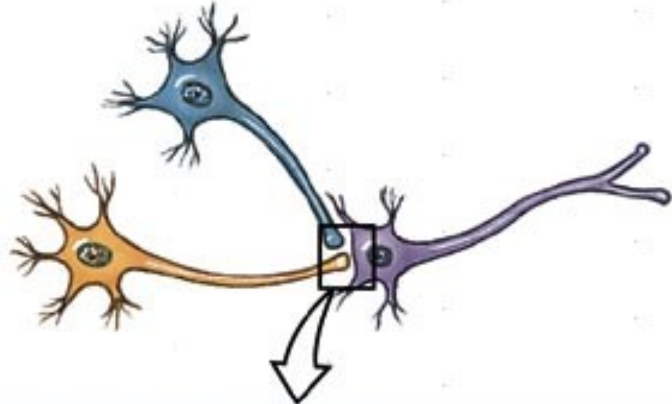
- A depolarizing postsynaptic potential (PSP) is called an **excitatory postsynaptic potential (EPSP)**.
- Although a single EPSP normally does not initiate a nerve impulse, the postsynaptic neuron does become more excitable; it is already partially depolarized and thus more likely to reach threshold when the next EPSP occurs.



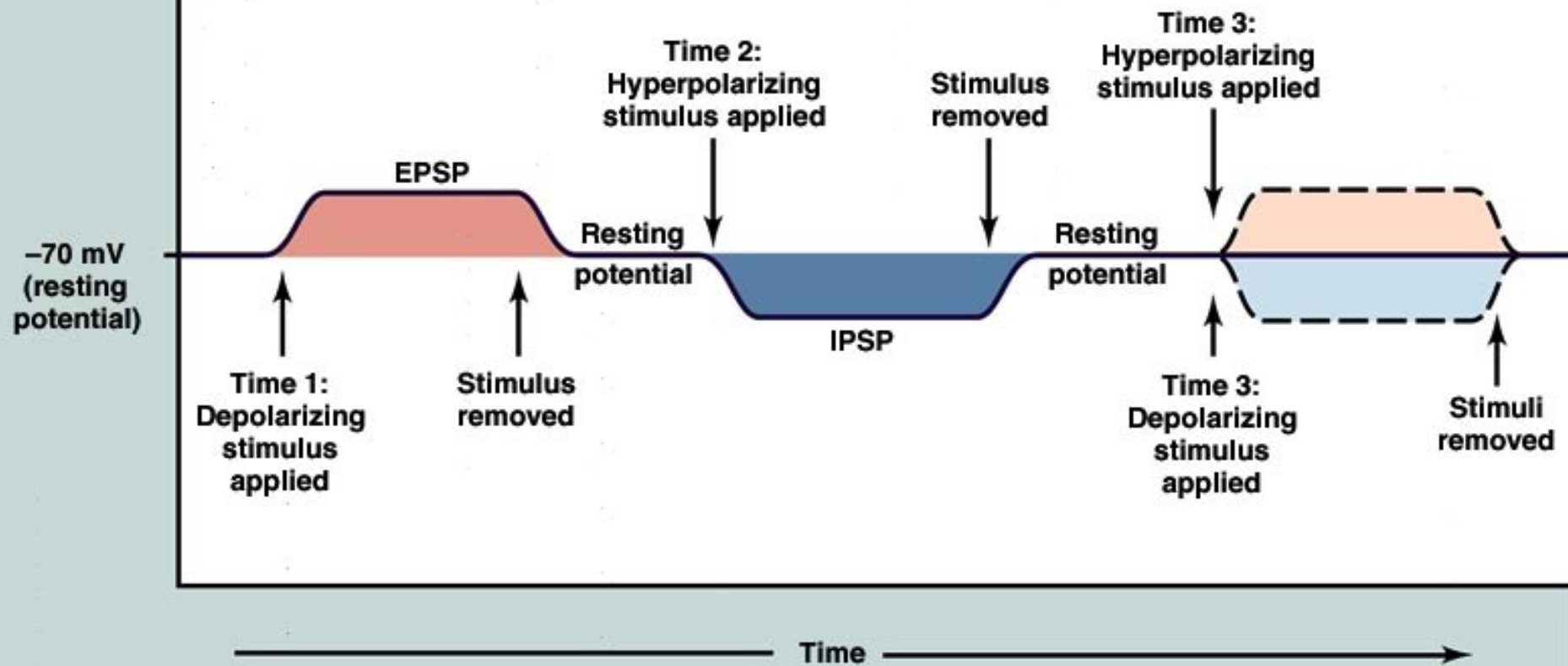
**(b) Presynaptic facilitation**

# Inhibitory Postsynaptic Potential (IPSP)

- An *inhibitory neurotransmitter* hyperpolarizes the membrane of the postsynaptic neuron, making the inside more negative and generation of a nerve impulse more difficult.
- A hyperpolarizing PSP is inhibitory and is termed an *inhibitory postsynaptic potential (IPSP)*.

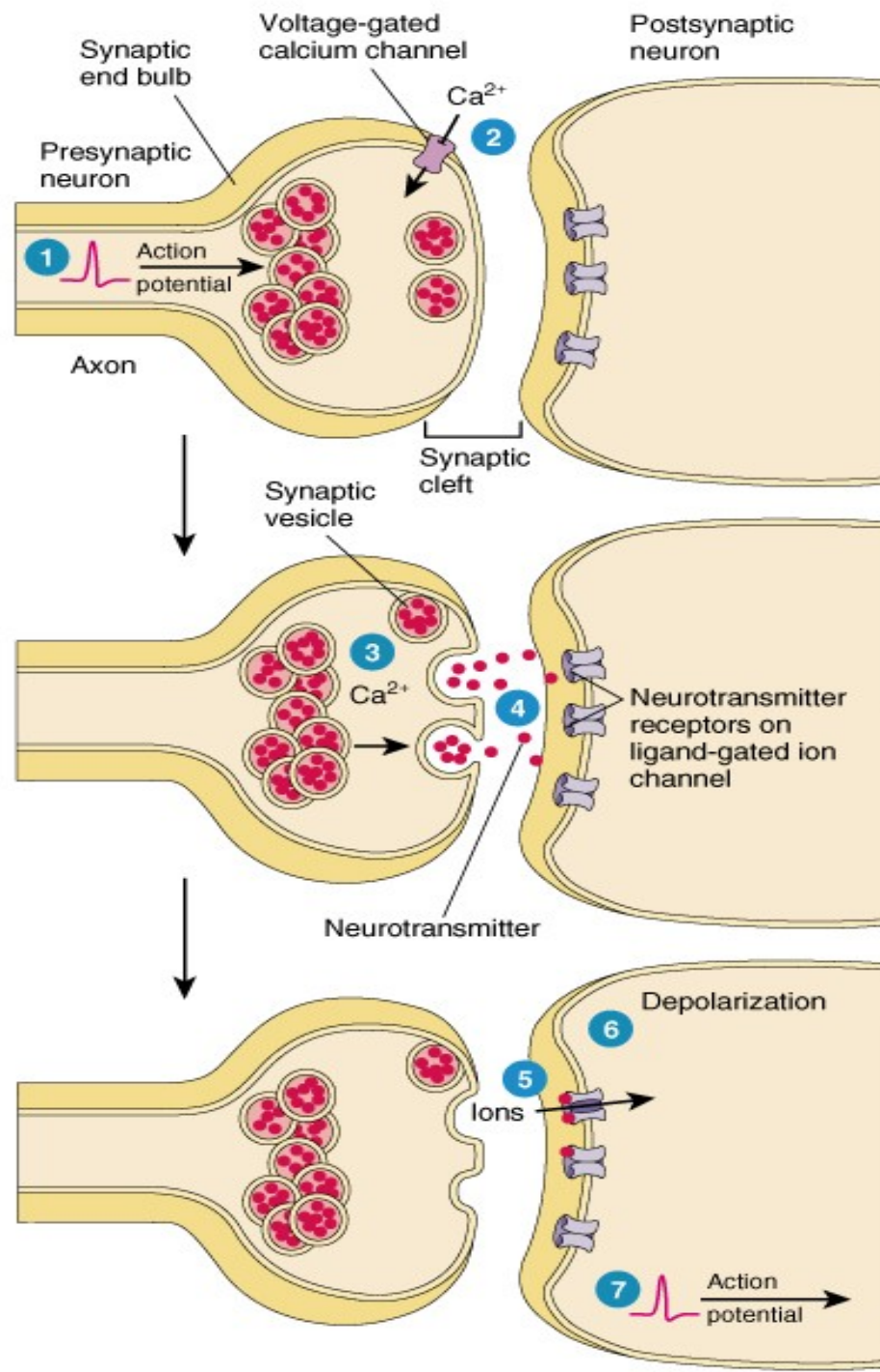


(a) Presynaptic inhibition



# Presynaptic Neuron End Bulbs

- If several presynaptic end bulbs release their neurotransmitter at about the same time, the combined effect may generate a nerve impulse due to *summation*; summation may be *spatial* or *temporal* .



# Postsynaptic Neuron

- The postsynaptic neuron is an integrator, receiving and integrating signals, then responding.
- If the excitatory effect is greater than the inhibitory effect but less than the threshold level of stimulation, the result is a subthreshold EPSP, making it easier to generate a nerve impulse.

# Postsynaptic Neuron

- If the excitatory effect is greater than the inhibitory effect and reaches or surpasses the threshold level of stimulation, the result is a threshold or suprathreshold EPSP and a nerve impulse.
- If the inhibitory effect is greater than the excitatory effect, the membrane hyperpolarizes (IPSP) with failure to produce a nerve impulse.

# Neurotransmitters

- Table 12.3 summarizes the structural and functional elements of a neuron.
- Both excitatory and inhibitory neurotransmitters are present in the CNS and PNS;
- The same neurotransmitter may be excitatory in some locations and inhibitory in others.

# Neurotransmitters

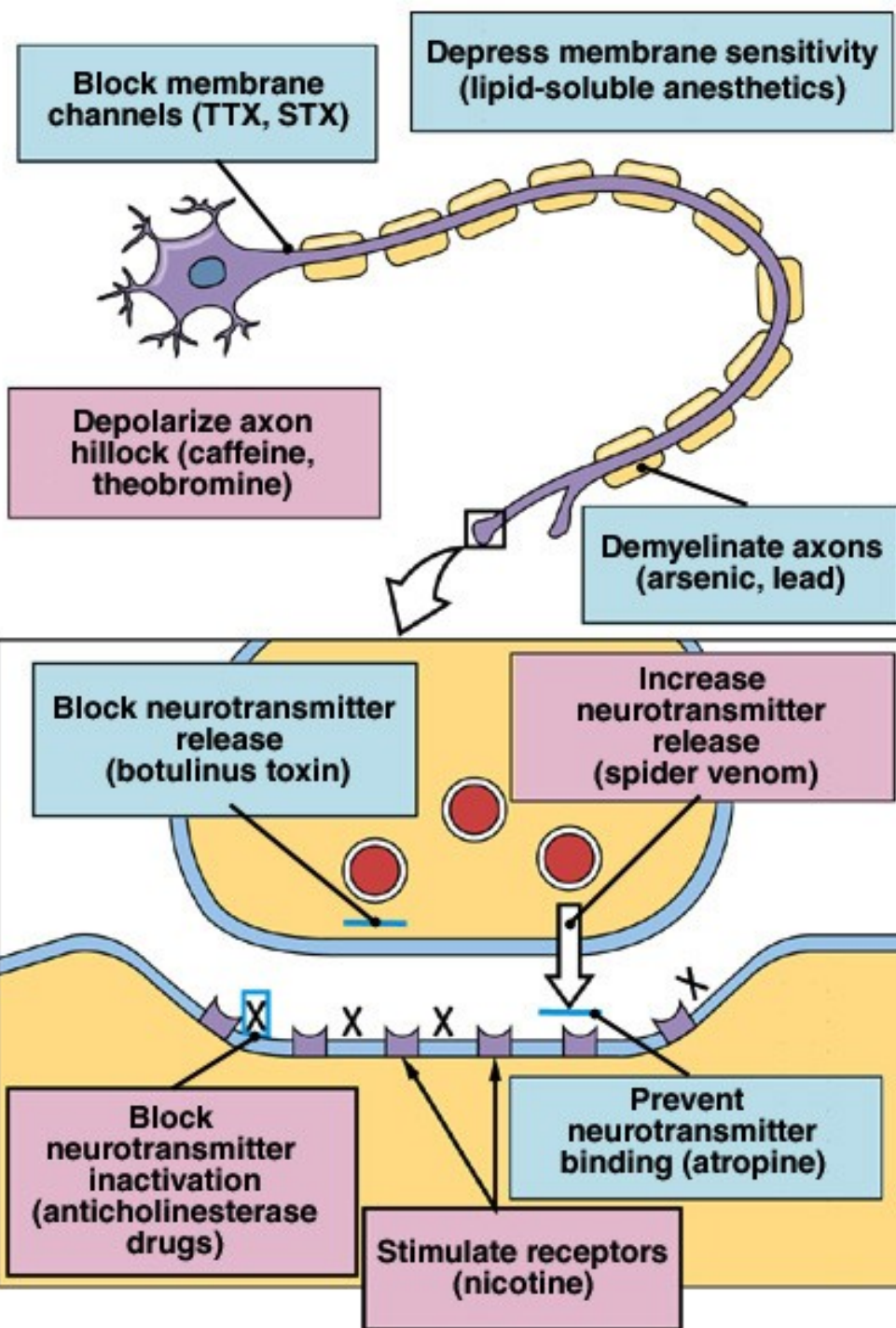
- Important neurotransmitters include *acetylcholine, glutamate, aspartate, gamma aminobutyric acid, glycine, norepinephrine, epinephrine, and dopamine.*
- Neurotransmitters can be modified by stimulating or inhibiting neurotransmitter synthesis, blocking or enhancing neurotransmitter release, stimulating or inhibiting neurotransmitter removal, and/or blocking or activating the receptor site.

# Neurotransmitter

- Neurotransmitters can be divided into two classes: ***small-molecule neurotransmitters*** and ***neuropeptides***.
- Small-molecule neurotransmitters include acetylcholine, amino acids, biogenic amines, ATP and other purines, and gases.
- Neurotransmitters consisting of 3-40 amino acids linked by peptide bonds are called **neuropeptides** (Table 12.4)

# Neurotransmitter

- Neurotransmitter is removed from the synaptic cleft in three ways:
- *diffusion*,
- *enzymatic degradation*,
- and **uptake into cells** (neurons and glia).

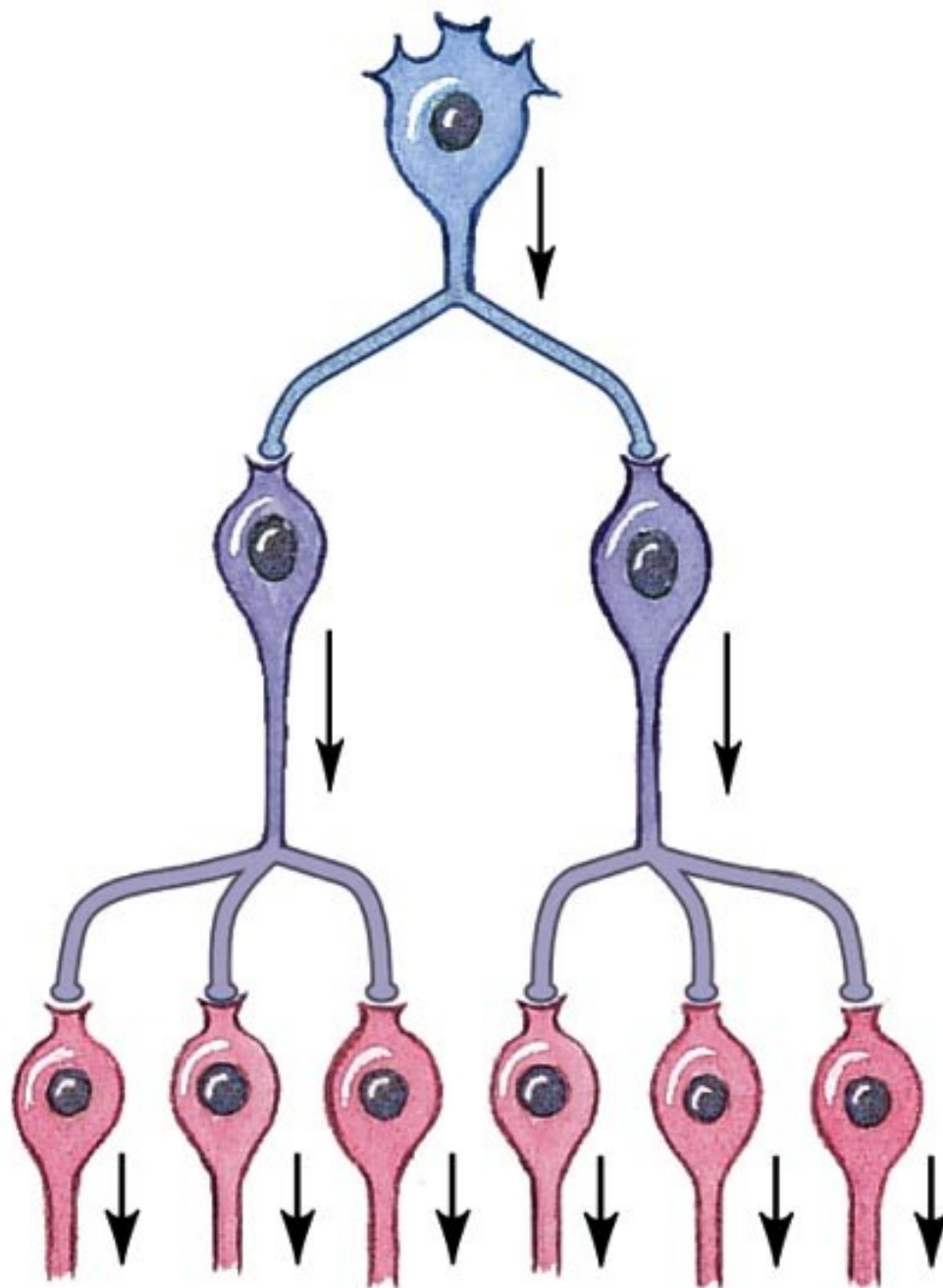


# CIRCUITS IN THE NERVOUS SYSTEM

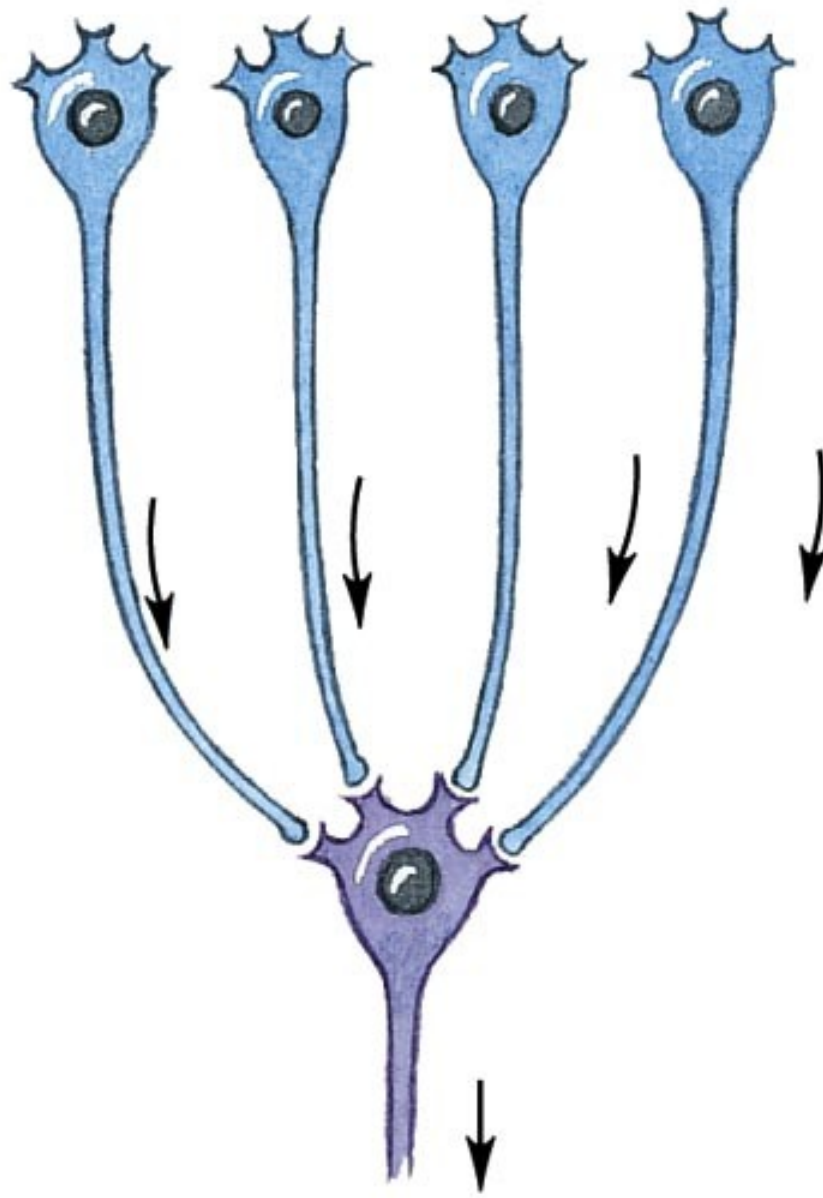
- Neurons in the CNS are organized into definite patterns called **neuronal pools**;
- Each pool differs from all others and has its own role in regulating homeostasis.
- A neuronal pool may contain thousands or even millions of neurons.

# **CIRCUITS IN THE NERVOUS SYSTEM**

- Neuronal pools are organized into circuits.
- These include simple series, diverging, converging, reverberating, and parallel after-discharge circuits.



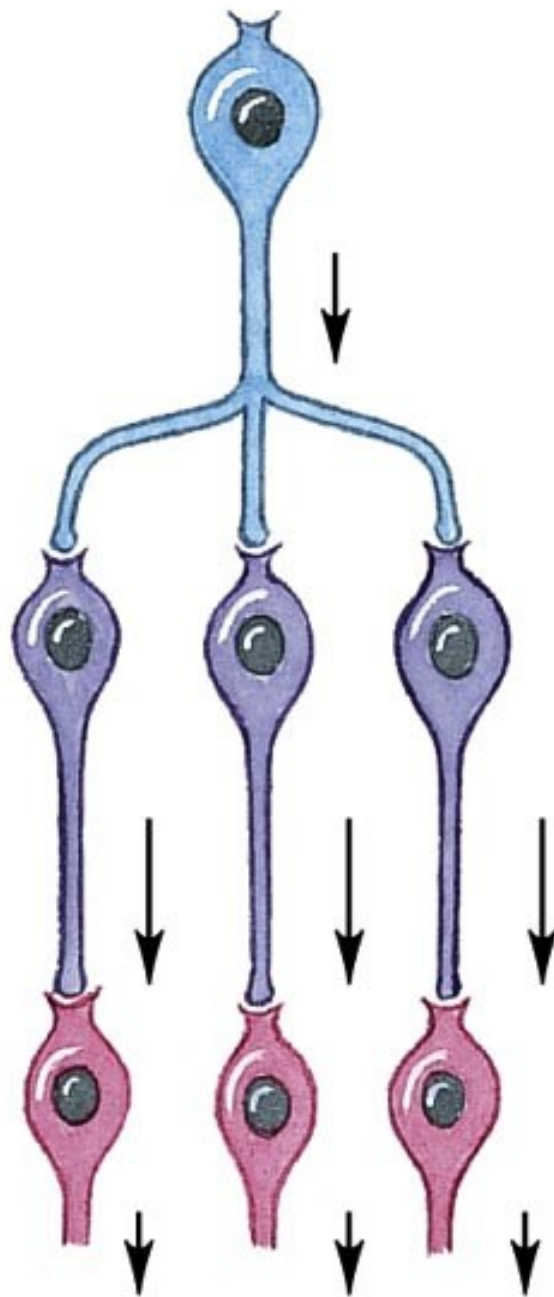
(a) Divergence



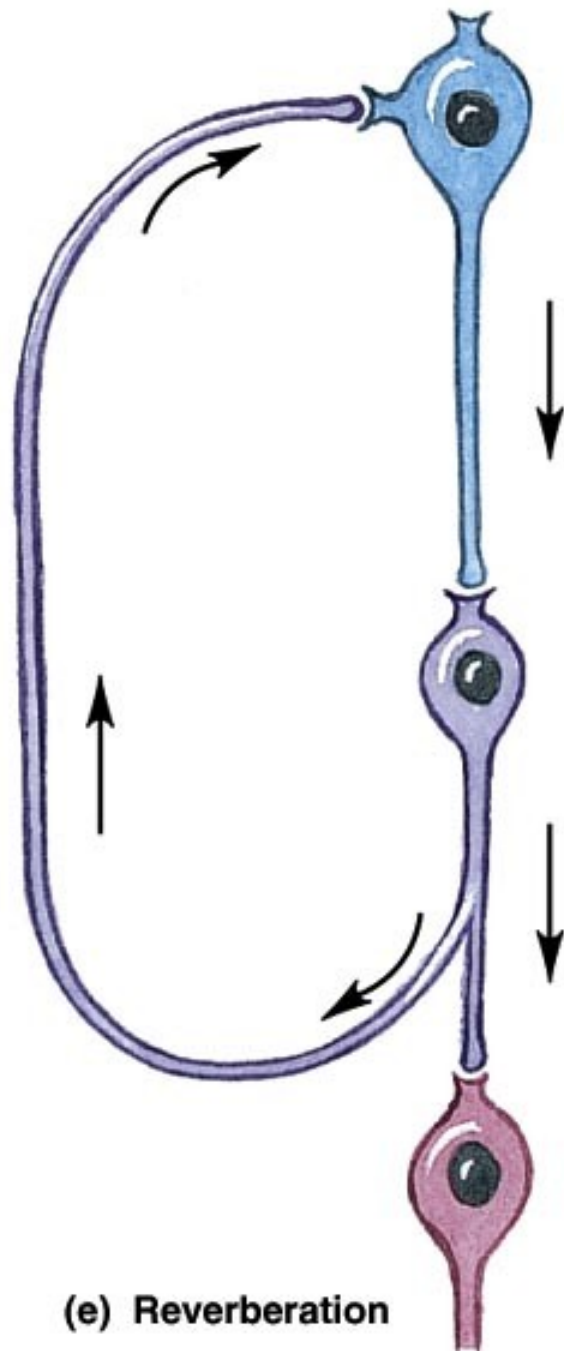
**(b) Convergence**



**(c) Serial processing**



**(d) Parallel processing**



(e) Reverberation

# REGENERATION & REPAIR OF NERVOUS TISSUE

- Throughout life, the nervous system exhibits *plasticity*, the capability for change with learning.
- Despite plasticity, neurons have a limited capacity to repair or replicate themselves.
- In the **PNS**, damage to dendrites and myelinated axons may be repaired **if** the cell body remains intact and **if** Schwann cells are active.

# REGENERATION & REPAIR OF NERVOUS TISSUE

- In the **CNS**, there is **little or no repair** of damage to neurons.
- Current research is going on to find ways to promote *neurogenesis* and to find ways to encourage and promote regrowth in the CNS.

# Damage & Repair in the Peripheral Nervous System

- When there is damage to an axon, usually there are changes, called *chromatolysis*, which occur in the cell body of the affected cell; this causes swelling of the cell body and peaks between 10 and 20 days after injury.

# Damage & Repair in the Peripheral Nervous System

- By the third to fifth day, degeneration of the distal portion of the neuronal process and myelin sheath (*Wallerian degeneration*) occurs; afterward, macrophages phagocytize the remains.
- *Retrograde degeneration* of the proximal portion of the fiber extends only to the first neurofibril node.

# Damage and Repair in the Peripheral Nervous System

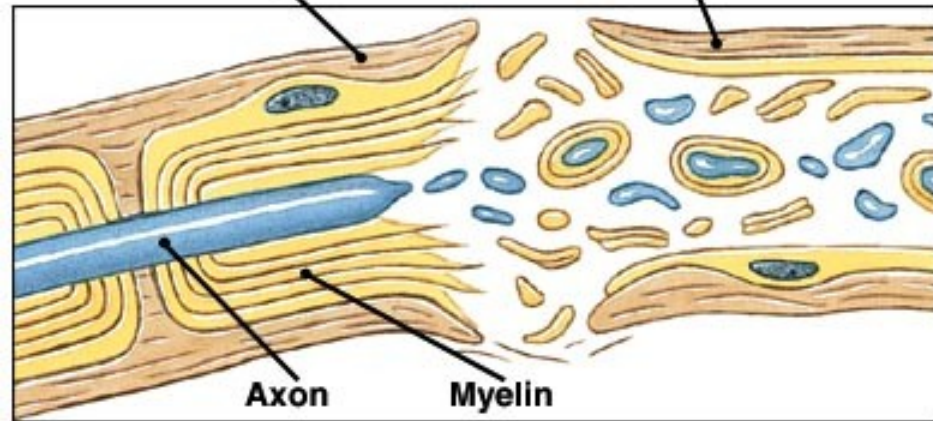
- **Regeneration** follows chromatolysis; synthesis of RNA and protein accelerates, favoring rebuilding of the axon and often taking several months.

Proximal stump

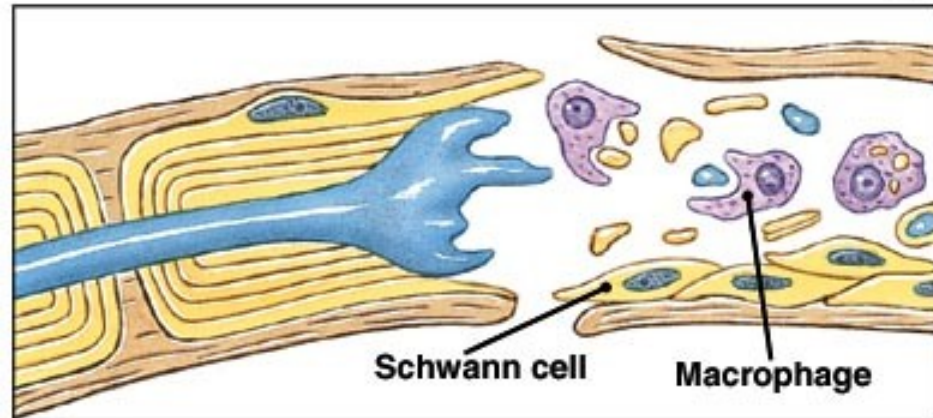
Distal stump

Axon

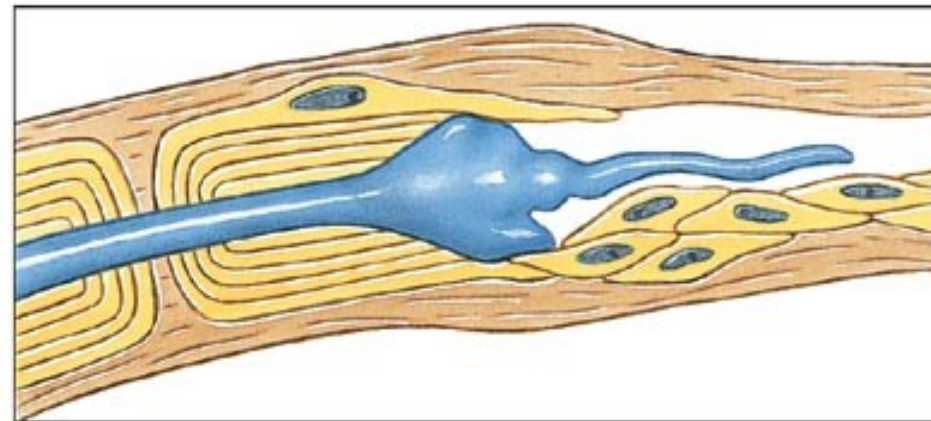
Myelin



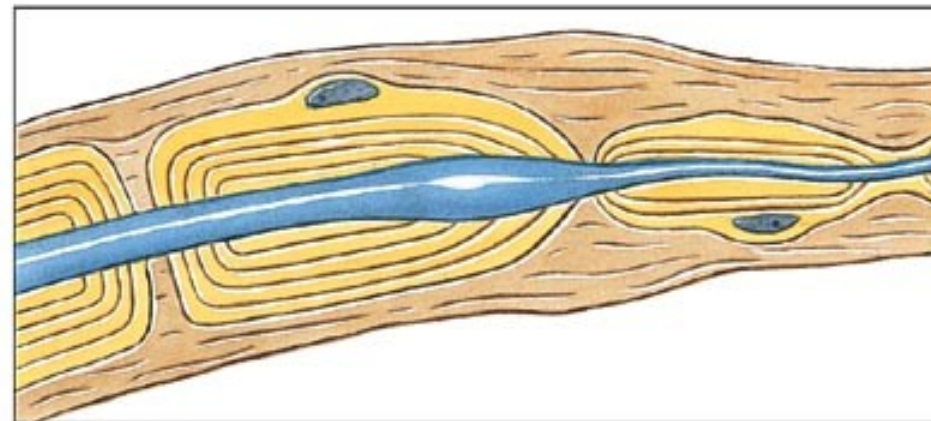
**STEP 1:**  
Fragmentation of axon and myelin occurs in distal stump



**STEP 2:**  
Schwann cells form cord, grow into cut and unite stumps. Macrophages engulf degenerated axon and myelin..



**STEP 3:**  
Axon sends buds into network of Schwann cells and then starts growing along cord of Schwann cells.



**STEP 4:**  
Axon continues to grow into distal stump and is enfolded by Schwann cells.

# DISORDERS: HOMEOSTATIC IMBALANCES

- Multiple Sclerosis (MS)
  - *Multiple sclerosis* is an autoimmune disease that results in the progressive destruction of myelin sheaths in neurons in the CNS.
  - Myelin sheaths deteriorate to scleroses, which are hardened scars or plaques, in multiple regions.
  - This is a progressive debilitating disease.

# DISORDERS: HOMEOSTATIC IMBALANCES

- Epilepsy
  - The second most common neurological disorder after stroke is *epilepsy*, which affects 1% of the population.
  - It is characterized by short, recurrent, periodic attacks of motor, sensory, or psychological malfunction called epileptic seizures.
  - These seizures are initiated by abnormal synchronous electrical discharges from millions of neurons in the brain, perhaps resulting from abnormal reverberating circuits.

# DISORDERS: HOMEOSTATIC IMBALANCES

- Epilepsy
  - Epilepsy has many causes, including brain damage at birth, the most common cause; metabolic disturbances, infections, toxins, vascular disturbances, head injuries, and tumors and abscesses of the brain. Most epileptic seizures, however, are idiopathic (i.e., they have no demonstrable cause).
  - Epileptic seizures can be eliminated or alleviated by drugs that depress neuronal excitability.

**PERIPHERAL NERVOUS SYSTEM**

**GRAY MATTER**

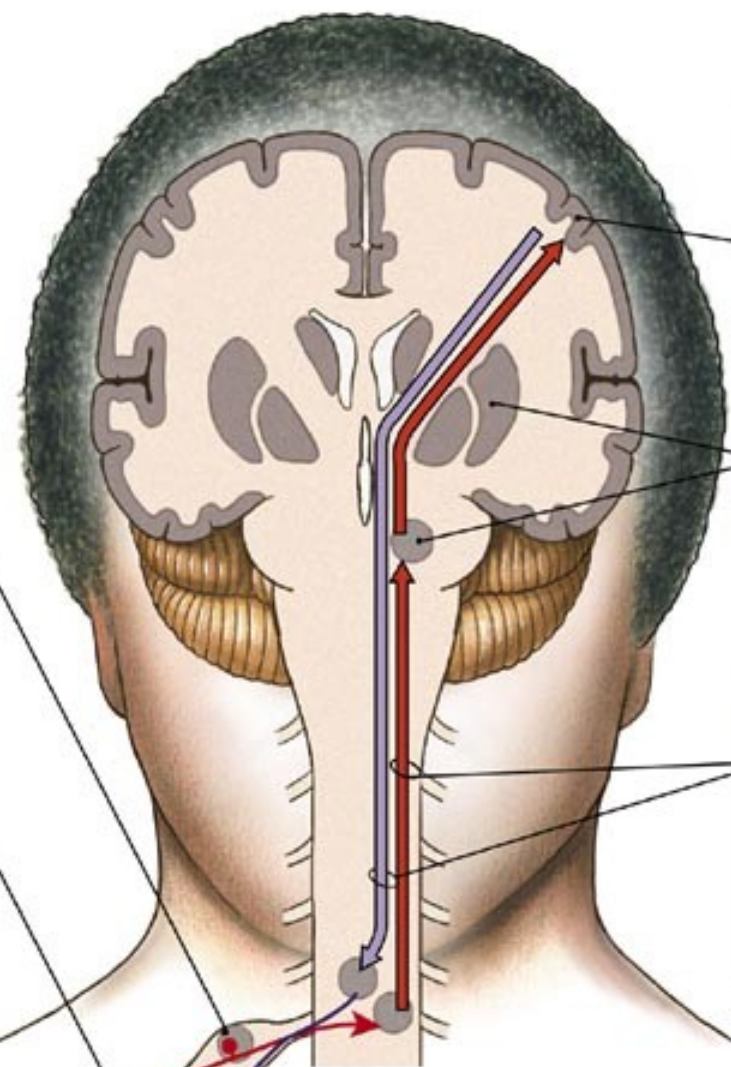
**Ganglia**

Collections of neuron cell bodies in the PNS

**WHITE MATTER**

**Nerves**

Bundles of axons in the PNS



**CENTRAL NERVOUS SYSTEM**

**GRAY MATTER ORGANIZATION**

**Neural Cortex**

Gray matter on the surface of the brain

**Nuclei**

Collections of neuron cell bodies in the interior of the CNS

**Centers**

Collections of neuron cell bodies in the CNS; each center has specific processing functions

**Higher Centers**

The most complex centers in the brain

**WHITE MATTER ORGANIZATION**

**Tracts**

Bundles of CNS axons that share a common origin and destination

**Columns**

Several tracts that form an anatomically distinct mass



**Pathways**

Centers and tracts that connect the brain with other organs and systems in the body

**Ascending (sensory) pathway** —

**Descending (motor) pathway** —

